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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SCIENCE AND HUMAN PROSPECTS

BY ELIOT BLACKWELDER

(Address as Retiring President of The Geological Society of America)

On facing the duty of preparing the customary Presidential address for this year, I gave some thought to the question of what contribution I could best make. Having been for many years a field geologist and at times even an explorer, I might have gathered up the results of many local studies and generalized them. Being engaged more recently in studying desert physiography and the Pleistocene history of the Western States, I might have chosen one of those subjects—and indeed they are well worth considering.

However, in such a fateful year as 1940, it seemed to me that the occasion called for a subject of greater importance and one that has a more direct relation to the welfare of this nation; and so I decided to ask your attention this evening to a subject that has long been one of my chief concerns—namely, education in Science and its relation to the future welfare of Humanity.

It seems to me that a teacher of Geology, or indeed of any other science, should devote himself not only to giving his students information, and explaining processes and theories—however important those educational duties may be—but especially to training young people in the scientific way of thinking and helping them to acquire the scientific spirit. To my mind, that is his most important function.

Since Geology is considered a science—albeit not one of the so-called exact sciences—and since we call ourselves scientists, it may be well to ask at this point, what, essentially, is Science? In general terms the dictionaries say that it is knowledge established, organized, and systematic. To me, however, this concept is not adequate. In the words of the great French mathematician, Poincaré: "A collection of facts is no more a Science than a heap of stones is a house." Verified knowledge is one element, organization and classification are necessary and so is the testing of hypotheses, but I cannot regard any of these as the core of Science. To me the basic thing about Science is an attitude or habit of mind, a way of thinking which is characteristic of those entitled to be called scientists. If that is so, most subjects of human concern may be dealt with in a scientific way. The essential basic condi-

tion is freedom from bias and prejudice. The major objective of the scientist is Truth, no matter how unpleasant it may be or how much discomfiture it may cause among those who hold cherished beliefs which happen, nevertheless, to be errors. Dr. Crapsey once remarked that: "Truth is a brand new virtue." And it may be added that as such it is not yet as widely sought and valued as it should be. It has been well said that "the purpose of Science is understanding." This is only a modern version of the well-known admonition of King Solomon to "get understanding."

The scientific method is relatively new. As recently as four centuries ago it was a rarity even among the most learned thinkers of the time. Today it is used only incidentally by most of the people in even the most civilized countries. It is hardly an exaggeration to say that the majority of educated persons—even those with college degrees—do not really understand it. Often it is confused with invention or the mere cataloging and classifying of knowledge. Some years ago, in a nation-wide poll which was taken for the purpose of finding out who was popularly considered to be the greatest scientist in the United States, the choice fell upon Edison, the inventor. But inventions, however useful and ingenious, are only the outgrowth, the by-products, of Science. Although invention was originally a matter of mere cut-and-try experiment it now makes more and more use of Science, until much of it is now highly scientific in the true sense. Even so, the one should not be confused with the other. Science is not invention. The purposes of scientists and inventors are fundamentally different, even when they use similar methods.

As for the majority of mankind, in the less-developed countries, their lives have scarcely been touched by Science except in the form of some of its tangible products such as machines, the radio, or by the services of the sanitarian; and their understanding of Science is hardly greater than was that of their ancestors a thousand years ago.

Even among the most cultured of civilized people some misunderstand Science so completely that they think they disapprove of it and consider it dangerous. Not infrequently do we hear the ills of the world today blamed upon the advances of Science, by which is evidently meant inventions such as dynamite, poison gas, or the airplane. Some writers have even called for a moratorium on scientific research, lest the dangers they ascribe to Science overwhelm our civilization. But we do not abolish automobiles just because criminals use them in bank robberies and child snatching. On the contrary, it would seem better to extend the scientific method to those fields of study which are not yet making the required progress. One might paraphrase a famous

remark about democracy by saying: "The best cure for the evils of Science is more Science"—at least better and more widespread Science.

The genuine scientist searches out the facts he requires, testing and evaluating them as he goes. He must try to discriminate the true from the false, and the trivial from the significant. His disciplined imagination, always at work even during the fact-gathering process, suggests explanations for the things observed—usually for the details and later, as the picture takes shape, for phenomena of wider scope. All these ideas must be impartially tested before they can be either accepted or rejected, just as an engineer determines by calculation the strength of the arches in a projected bridge, and for a similar reason. How high shall we appraise the value of the fortunate speculator who happens without much evidence to hit upon the right explanation far ahead of others, as compared with the patient investigator who carries a firm structure of fact and controlled theory with him all the way? The former has uses, but it is chiefly to the latter that steady scientific progress is due. Loose speculation is an ingrained habit of humanity, but the careful scientist realizes that many problems are now insoluble because the necessary data are not yet obtainable. He will, therefore, restrain his fancy, devoting his efforts to objectives that are within his reach, content to leave to his better informed successors those other questions which are not yet ripe for consideration.

The critical testing of ideas is a habit difficult for the average human being to adopt. An original idea is a brain-child and tends to be jealously cherished as such. To expose it to the cold light of reason takes a sort of Spartan courage that is too often undeveloped and yet is one of the essential attributes of anyone who aspires to be called a real scientist. To be merely logical with facts selected for a purpose is much easier than to divest oneself of bias. Steadfast courage and a renunciation of false pride are required in the search for opposing rather than supporting evidence.

The unrealized assumptions hidden in his theory are the sunken rocks on which the ship of many a hopeful scientist is wrecked. Our literature affords examples without number, especially in the earlier times. Geologists will find a good illustration even in the writings of that thoughtful old Scot who is regarded as the founder of their science—James Hutton. Writing about the granite boulders from Mont Blanc that are sprinkled over the slopes of the Jura Mountains near Geneva, he concluded that the Rhone River must have excavated its valley after they were deposited. The erroneous assumption, hidden in his mind and unrecognized, was that only streams could have moved the boulders, and he knew that streams

cannot flow up hill. He overlooked the glaciers, although it is evident that he already knew something of their power and habits. Perhaps he assumed that those he saw around Mont Blanc had never been much larger than they were in his day.

Failing to understand what the real scientist must be and what the essentials of Science are, part of the public today is led to accept as Science various elaborations of intuition, speculation, and fancy, such as were much more widely current a few centuries ago. To the practitioners of this pseudo science, David Starr Jordan (1924), in a humorous paper, once gave the name "Sciosophists." The term, he explained in mock seriousness, comes from two Greek words, *skios* meaning shadow, and *sophos* meaning wisdom, or in short "the shadow of wisdom." Sciosophists, he said, are happily free from the ordinary limitations of Science for they are not hindered by the need of evidence. To them one idea is as good as another, and so why go through the laborious process of examining facts, searching out all the evidence, and testing each explanation before accepting it? A glittering and imposing structure can be built up with ease by a sciosophist out of many such unverified suppositions; but, of course, Jordan scarcely needed to say that it is as vulnerable to critical analysis as a child's tower of blocks is to a touch of the hand. It is regrettable, but in a free country perhaps unpreventable, that the cloak of Science should be donned and worn by faith-healers and other mystics who have no comprehension of the meaning of the term. As a result, however, it is hardly surprising that part of the general public has a rather confused impression about Science, when it reads serious accounts of such absurdities as a "science of Astrology," "the science of Phrenology," and many others.

That the scientific method had its beginning in the ancient Greek and probably even earlier civilizations is clear enough, but it was displayed by only a few of the philosophers of that era and not consistently even by that few. This is all the more strange in view of the fact that the art of reasoning—logic—was highly cultivated by the Greeks. True, men like Anaxagoras at Athens had many sound ideas and employed the scientific method to a notable extent, but at the same time they entertained, as firm beliefs, some notions that would now bring a laugh to any school-boy.

If one examines the writings of the founders of ancient Greek Science in the sixth century B. C.—men like Thales and Anaximander—he finds that many of their opinions were mere suppositions, elaborated and bolstered with such support as labored argument and ingenuity of words could give. These men were the precursors of modern scientists but can hardly be called scientists themselves. No true scientist would have seriously

put forth as a conclusion so fantastic and wholly unverified a notion as the great Aristotle's dictum that earthquakes are due to the surging of the wind through caverns in the earth. Even allowing for the inaccuracies of translation from the Greek, one can find only the slenderest evidence to support this opinion. It was a result of pure speculation upon a subject about which the author had not even the most elementary knowledge. Yet it was quoted with approval for 20 centuries. This is all the more inexcusable because a considerable body of definite information about earthquakes was available in the Greek world of Aristotle's day, and there were many pertinent observations on geology that could easily have been made in that epoch, even without modern instruments, if serious attention had been devoted to the problems.

In its early stages the cultivation of Science was often too largely a contest between champions of rival theories. In ancient Greece the celebrated master gathered about him a group of disciples who too often came to regard his pronouncements as infallible. In the school of such a man as Pythagoras of Sicily, to quote the leader was sufficient to settle any disputed point. The ideas of the master thus became dogmas and took on a kind of sanctity.

It must be admitted that dogma has been the fashion of the past. For millions of the earth's inhabitants it still remains so. Today we see the current of progress being reversed in the despot-ridden countries of Europe, where the privilege of freely drawing conclusions from evidence is being restricted and the blind acceptance of official dogma is exalted as a duty, if not a necessity.

Even in the last century or two the history of Science was marred by many a bitter controversy between rival leaders and their followers over theories. A theory was defended like a home citadel, and doubters were considered enemies actuated by the darkest of motives. Among such bickerings there was by contrast the magnanimity of Charles Darwin who said, regarding the storm of criticism that raged after the publication of *The Origin of Species*, "If my book can not stand the bombardment, why then let it go down and be forgotten."

Fortunately, rancorous disputes have nowadays largely ceased to afflict the relations of real scientists. Yet there is still far too much of that spirit in the world at large. It has been well said that "Most men think with their emotions rather than their intellects." The ancient method of verbal combat is still employed in our law courts and legislative halls. Each participant adheres to his thesis. Search is then made for evidence to support it and at the same time to refute its opponents. An equal effort is made to suppress or depreciate any facts that may prove to be embarrassingly adverse.

The debating society may be a good place to train lawyers, but the partisan attitude of "win the argument and confound the opponent" is an unhealthy state of mind for a young scientist. Indeed, he can never become a true scientist until he outgrows that mental attitude. Rather he should cling to the advice of that wise old Quaker, William Penn: "In every debate, let *truth* be thy aim, not victory." Perhaps it is our sporting instinct, derived, it may be, from our age-long struggles against each other, that makes us usually more interested in winning a contest than in finding the truth.

By those who have not considered the matter thoroughly, scientists are often adversely criticized for devoting so much of their energy to problems that seem to lead to nothing of any human value. No doubt there is considerable merit in this charge. But we shall never know to what extent it is justified, because we can only guess what kind of knowledge and what kind of understanding may become useful in the future. The history of Science is full of examples supporting this statement. Our huge electric motor industry grew out of the simple discovery by Faraday that when a magnet was moved in a loop of wire an electric current was generated in the wire. Why should the knowledge of that bare fact have been of much value, and why should the public have been impressed at the time? In fact, it was not. Only a few men of Science gave it some attention, as revealing a new principle—that of electromagnetic induction. Similarly, the oil industry of Texas has been greatly aided by the intelligent combining of many bits of scientific information no one of which by itself has much commercial value—such items as undulations in strata, earth vibrations, soil analyses, and Foraminifera in drill-hole samples.

Although the gathering of facts cannot in itself develop a science, yet facts we must have, in infinite number and variety, even though they are only the bricks to be used by the builder. The mere multiplication of facts, the piling up of observations closely similar to hundreds of others, is properly regarded as of less value than the search for explanations, principles, and laws. While the layman thinks of Major Powell as the intrepid explorer of the Colorado River and its Grand Canyon, discovering, even at the risk of death, the wild beauty of its scenery and the details of its geologic section, it is fitting that geologists should honor him even more for his clear exposition of the principles of the base level of stream erosion and the antecedent river.

In view of the fact, already mentioned, that we can seldom foresee what utility any scientific fact or principle will eventually have, we cannot afford to neglect any aspect of Science. Discoveries in one field often

release obstructions that have held back progress in other branches of Science, and thus permit further advances. On the other hand, by regimenting scientific work and even opinion, along with all other phases of life, for their own immediate purposes, modern tyrants are violating this principle. This they can do with some measure of success for a short time, but eventually their countries will almost surely suffer a degeneration of Science, and therefore of the civilization which is based upon it.

Along with the increasing complexity of modern life there has grown up an urgent need for the scientific expert. The demand is being met by many persons who are real scientists but unfortunately by others who do not deserve the name. On that score Dean Roscoe Pound lately said in sarcastic vein that "the administrator is not appointed to office because he is an expert but he is an expert because he has been appointed." We all know of cases that fit this satire, but in all seriousness we may trust that they are not numerous and that they are decreasing.

Since the public must depend on its experts, it is essential that it should be well justified in placing confidence in them, to the end that such respect will endure. That puts a heavy responsibility upon the individual expert. As Grover Cleveland once said "a public office is a public trust," no less so should any degree of leadership in Science be regarded as a public trust; and so the expert scientist is under great obligation to deserve the confidence of the public. His intellectual honesty will need to be outstanding and unwavering. Today, in this country, the scientist has already won such esteem to a large degree, although he is compromised and discredited now and then by the shortcomings of the less conscientious and careful of his colleagues. Unfortunately, too, it is among the latter that the most vocal types are apt to appear, and it is they who often attract the most public attention. Perhaps it is expecting too much of Man, as we know him, to hope that a time will someday arrive when our most influential leaders will be persons who have the true scientific spirit and have been trained expressly for the work they are to do, as humble in the face of their own limitations as they are wise and honest.

Many years ago, a former president of our Society, R. A. Daly, speaking informally as a visitor to one of my classes, advised the boys to "think to scale." It would be hard indeed to pack more meaning into three words. The person who *thinks to scale* sees the relative value of each fact he uses and of each objective before him. He can then economize his time by confining his attention chiefly to the important and the significant problems. On that point the wisest of the Roman emperors, Marcus Aurelius, is said to have remarked that "Every man is worth just so much as the things are worth to which he devotes his earnest efforts." It might

be somewhat disquieting to many of us if we should measure ourselves by that principle.

More than three centuries ago Sir Francis Bacon urged the application of the scientific method, as he then conceived it, to human affairs and problems in general, but we are still far short of having adopted his advice, although all our experience since his day confirms its value.

The greatest progress has been made thus far in the physical sciences and scarcely less in the biological. The scientific method and attitude of mind also pervade to a very large degree the related professions of Engineering and Medicine. Engineering and invention, based in increasing measure upon Science and pursued largely in the scientific spirit, have given us nearly all our modern transport and communication facilities, our great water control and power devices, our vast numbers of useful and convenient new materials such as rayon, plastics, alloy metals, and other benefits too well known and too numerous to mention. But for the application of medical science we should be decimated not only by typhoid, tuberculosis, and small-pox, but also by yellow fever, cholera, and even the plague. Were it not for the deficiency of science in politics, statecraft, and ethics we might not find ourselves today threatened by the plague of military despotism, which is more deadly in its modern form than any pestilence. We have used the scientific method in Engineering and Medicine for a century and have found it good—far more effective than the old ways of speculation or of trial-and-error. In spite of the difficulties involved, why not then extend it to other fields? Is there any reason to suppose it will not bring great improvement there also?

In such fields of study as Economics and Sociology, the complex and fluid nature of the basic data that must be used and the influence of human prejudice, which closely touches these subjects, have greatly impeded their emergence from speculative philosophy and their rise toward the scientific level. In addition they need a more general adoption of the scientific attitude and method. Why not apply these to human affairs, subdue the emotional considerations, and brush away the cherished errors of the past? Then we should be able to move more rapidly toward a real understanding of principles, for we are justified in believing that such principles do exist.

In Ethics, which is in some respects the most important of all subjects of human inquiry, we have made no great progress beyond the Greeks of Aristotle's day; and most of them were, except in mathematical studies, philosophers rather than scientists. Even today the study of human conduct is but slowly emerging from its age-long status as an appendage of religion. Would it not bring fruitful results to study Ethics in the same scientific spirit that already pervades such a field of research as Physiol-

ogy? Without a firmly based and widely accepted science of Ethics, the other natural sciences alone may lead us eventually to ruin for want of adequate control. Under the direction of the engineer, dynamite is an effective aid in construction and promotes industrial progress; but in the hands of the criminal it means murder and destruction. The difference is only one of ethics.

To have Science flourish, there must be complete freedom of inquiry and discussion. The beneficial influence of such freedom is indicated by the extraordinary development of Philosophy and the sciences among the Greeks in the fourth to the sixth centuries B. C., in the Germany of the nineteenth century, and in modern America. Scholars properly insist on this necessity and guard their hard-earned right to intellectual liberty; nor is this freedom of research so firmly held but that it takes a little defending all the while from the bigots who would close to discussion certain trends of thought of which they chance to disapprove.

But if the scientist is to deserve and therefore keep his freedom, even in a democracy, he should be equally scrupulous about his own responsibility to the public. He has no right to claim on the one hand immunity from restraint and on the other license to be unreliable. It is the few irresponsible members of our profession who endanger our freedom of expression, for it is their words that tend to discredit the very science to which they are nominally attached and thus bring all Science into disrepute.

One of the best indicators of the scientific maturity of a nation is the standing accorded scientists in their own communities. In Greece, Science and Philosophy flourished not only because they were free but because they brought honor and even wealth to those who distinguished themselves in scholarship. In Germany 40 years ago the great scientist, like Helmholtz, was appointed a Geheimrat and on the whole stood higher in the social scale than the banker or the industrial magnate. In our own country we are lately beginning to appreciate our thinkers, but their value to the world is not widely comprehended, nor are we very discriminating in recognizing them. We are apt to rate too highly the man who makes a spectacular but very definite and easily apprehended discovery, as compared with another who slowly develops an idea or principle which in time unlocks for us another room of progress.

Jefferson, Franklin, and other founders of our American Union fully realized that a well-informed people was essential to the success of the republic. Although a lover of freedom, Goethe understood the difficulty of making a democracy succeed, remarking that "the trouble with democracy is that it has to wait for an enlightened public opinion." More pessi-

mistic commentators, like Disraeli, were confident that the experiment could end only in failure, because they believed that even the best popular education that was practically attainable would be inadequate.

A system of education, to be good, must be suited to its time in history. The boys of ancient Persia were taught "to ride and to shoot and to speak the truth." In their day, nearly 3000 years ago, that was education enough, but now it would be of little avail, although the last item (speak the truth) has eternal value.

If we were willing to accept the Nazi plan of society we should need only a small highly educated upper caste. The rest of the people would be given only training and indoctrination. But if we want freedom and the socalled democratic way of life, then we need the most widespread and effective education that our mental equipment will permit. In our own system, a few wise leaders would be helpless in the face of a grossly ignorant populace, swayed chiefly by its emotions and prejudices. Too often this has been true in democracies thus far, and in America it is still a dangerous factor. So I conclude that we must have, as soon as we can provide it, far better and more extensive education, and a general adoption of the scientific attitude of mind. Is that a large order? It surely is—perhaps too much to expect—but it may well be the price of our liberty and the survival of the American type of civilization.

Hitler is quoted as having said that no people is capable of governing itself or even of planning its own affairs. If the majority of the people are to be kept in ignorance, he is doubtless right. As our life becomes more complex our problems become more difficult. To solve them badly may mean disaster. To solve them well requires adequate knowledge and especially clear thinking. Bias and prejudice are liabilities or handicaps that we cannot well afford and hence should try by all means to reduce. If, in a republic, we are to have affairs well handled, we must rear millions of capable unbiased persons to make those varied problems their life concerns. That, it seems to me, demands the scientific attitude of mind and an efficient system of education expressly devised for that purpose; for it is not something which we gain by inheritance or in the common experiences of life.

To insure a well-informed and intelligent people is a most difficult task. History affords no good example of such a nation. It is by no means certain that it is even possible. The eugenicists will properly assert that their advice must be followed, and no doubt there is some hope in their principles and plans; but beyond that it seems evident that education is our best chance. It means educating more people and educating most of them longer—perhaps continuously throughout life.

Most important of all, it means educating them far more wisely and efficiently. As a scientist I am perhaps biased in believing that the most important element in this education is the scientific attitude of mind. That does not mean that every person must become a scientist, but that he must acquire the habit of thinking as a scientist. It means that the great majority should understand what Science is, what it stands for, and its value to society. They should then be able to recognize the true scientist and distinguish him from the sciosophist or the imposter. It will also enhance their capacity to judge the merits of their leaders and the general issues of the day.

Having harped at length on the importance of Science, I must ask you not to misunderstand me as implying that Science is all we need. It is no panacea for our troubles. Indeed, if we were exclusively scientific we should not be human at all. There are other things that are also necessary—love, art, imagination, intuition, loyalty, poetry, and many others. I merely emphasize the opinion that Science is one of the most indispensable factors in civilization. We must become more scientific and especially more widely scientific.

To say that one vital function of society is more important than another is as pointless as to say that the lungs are more important than the heart. We may, however, be sure that effective education is one of the indispensable concerns of a free civilized nation. In the opinion of Dr. Copeland (1928) "education is incomparably the most important function of Society." Without it the state could not endure for even a century, for in no other way can the long slowly won progress of the past be effectively transmitted. Good education is one of the greatest means of national advancement. Poor education insures the decline of a people and even their disappearance as a nation.

Many of the ablest thinkers in the past, from Plato down to our own day, have felt sure that democracy was an unworkable plan. Much as I hope that they were mistaken, I should feel constrained to agree with them if I did not have some grounds for hoping that we can devise and continually improve a process of education adequate for the requirements of the country; but it will need to be much better than anything we have had thus far. This hope is encouraged by the view of so experienced an educator as ex-President Morgan of Antioch College, who has said that "results as revolutionary are possible in education as in engineering, and they are even more necessary."

Conditions in our schools and even in our colleges and universities today are far less satisfactory than they should be in view of our acute

need of the best education we can provide. As recently remarked by Professor Curtis (1939):

"even in this so-called scientific age we find, among our high-school, college and university graduates, many who believe nothing definite and have no convictions, while many others will believe anything, no matter how fantastic . . . there is little difference between many college graduates and those who have not gone beyond the eighth grade, insofar as their mental attitudes or judgments in the fields of science are concerned."

This he is inclined to ascribe partly to the fact that many teachers, as well as students, have had little or no training in science and partly to the type of teaching that is all too prevalent, especially in our lower schools. Too much of it is dogmatic, and the student is not trained to think for himself. There is far too much emphasis upon the learning of facts, on the mistaken supposition that knowledge, as distinguished from understanding, is the chief object of schooling.

Since in order to progress we must constantly improve our education, we shall have to have more teachers, especially better and wiser teachers, and teachers who are not only competent to train youth but who are allowed to utilize their competence in teaching, under a minimum of administrative control. In my opinion no mature teacher who needs to be told by a principal or dean how to teach deserves to be employed as a teacher. There has grown up in recent years a widespread tendency to overstress the importance of teaching methods and to give school executives wide powers of direction over the daily work of the individual teacher. Such practice overlooks the fact that good teaching is a matter of individuality, that the teacher to be successful must be a true scholar, and that scholars cannot be regimented. Also, our system has always been less effective than it should be, because we have left so much of the education of our rising generation to relatively inexperienced young persons. This seems almost as shortsighted, and in the long run as likely to prove disastrous to the Nation, as to leave our military defense largely to young recruits. The only apparent advantage to this is that it is less expensive than the alternative; but the cheapest system may prove in time to be the least economical.

At this point it may be asked what results we can fairly expect from such improvements in our educational arrangements in the next decade or century. The experienced scientist will understand that sound improvement in human affairs will come only by evolution and after cautious experiments on a small scale rather than by sudden revolutionary changes on a large scale.

One of our greatest dangers lies in the impatience of many people to gain great results quickly. This is natural enough, in view of the brevity of our individual lives. But it is inconsistent with the principles which

govern all life. We are a part of Nature and, however much we may seem to influence natural processes, there is every reason to believe that we are in fact and on the longer view controlled by Nature. Whether we like it or not, slow evolution is Nature's way. And so we can hardly hope to elaborate some theoretical new scheme of social or economic organization, put it into practice on a national or world-wide scale in a few years, and have any reasonable prospect of success. Hidden faults and weaknesses are likely to cause failure, and that in turn may exhaust for decades even the healthy impulse toward improvement. The fascination that these schemes have for our youth doubtless has a complex cause, but it may well be due in part to the faulty character of our current education, which has not given them the advantages of the scientific viewpoint. Again, as Daly said, they should learn to "think to scale."

However difficult it may be to forecast future trends more than a few years ahead, the geologist can hardly be expected to overlook the longer view; and so I may now raise a few questions about what may be in store for Humanity in another epoch—not a matter of centuries but probably of tens or even hundreds of thousands of years.

There are many who expect that Man will make continuous progress toward higher and better things, becoming in the course of time so much wiser, more sensible, and reasonable that the world's life will be vastly more happy than it has ever been in the past. War, sickness, and poverty would then be abolished. Cruelty, hate, and injustice would become obsolete, and we should be living in a sort of Golden Age the like of which we have never even approached. That is a beautiful vision to contemplate, especially in these dark times.

The lessons of Historical Paleontology may throw a beam of light ahead on this speculation, for of course it is no more than that. As we look back over the history of Man we find evidence of great cultural progress since the time of the primitive cave man, who made crude stone implements but lived in isolated families competing with the wild beasts of the day for such food as could be found or seized. He was indeed only one of the beasts, and it is hard to point out more than a few respects in which he was superior to them. Did the early Stone Age men gradually develop, by slow practice and learning, into modern Man? We do not know, but there is little reason to suppose so. All that we know today of Human Paleontology indicates that what we loosely refer to as Man comprised a group of at least five and probably eight or more distinct animal species which are generally grouped by zoologists in several genera. These may have originated in various parts of the world, each lived many tens of thousands of years, and then with one exception all became ex-

tinct. At certain times two or more such species may have coexisted, although probably in different regions. Perhaps they eventually killed off each other, just as the white race in historic times has exterminated the Tasmanians and certain other primitive tribes. But today only one species survives, and he has apparently had the field all to himself since the middle of the last glacial epoch, or about 30,000-50,000 years ago, according to current estimates. Each of these species appears to have been as distinct from the others as species and genera of animals usually are.

There is nothing to indicate that the very primitive *Sinanthropus* made much progress in culture during his long career in China. He learned to use fire—probably to make it—and to fashion a few simple tools of stone and bone; but that seems to have marked the limit of his inventive capacity. For shelter and safety from attack he seems to have crept into caves, like many another beast.

Neanderthal Man, generally placed in the genus *Homo,* shows evidence of a distinctly higher culture. He made more varied and better tools of chipped flint, of wood, bone, and other materials ready to his hand. But with a brain which appears to have been inferior, even his long career as a species seems not to have sufficed for him to invent pottery, polished or ground stone tools, to learn to domesticate and use other animals rather than to hunt them, or to grow crops, not to mention building houses or using metals. Apparently he had some ideas about spirits and a future life, for he buried his dead with same care and placed in their graves some of their ornaments and weapons; but we have no evidence that he developed any art of drawing or sculpture, and none of his tools were finely wrought. There is evidence of only slight progress during the long age through which he lived, and at his best his cultural level was distinctly lower than that of the most primitive savages now known to anthropologists.

How these various species of men came into existence is unknown and may well remain so. But there is nothing to suggest that their origin differed in any way from that of the other mammals. To suppose that it did would be gratuitous speculation. Indeed, had it not been for the achievements of the latest of these species, the Hominidae would never have been entitled to special notice as anything more than somewhat peculiar mammals.

From biological friends whom I have consulted, I learn that they are not yet agreed upon the question of how a new species originates. In fact there is some difference of opinion as to just what constitutes a species, as contrasted with a race, a variety, or even a genus. While

waiting for the biologists to work out these problems, we may use the term *species* a bit vaguely in its current meaning, and we may tentatively adopt the now preponderant view that new species originate not by gradual imperceptible changes but by sudden mutations, either extensive enough to produce a distinct species at once or occurring in series which eventually culminate in full specific status.

However any new species actually originated, its parental species doubtless continued to exist for a time without much change. The new kind expanded in numbers and, if more effective, eventually overran and exterminated the older one. It then went on living without important physical change until it was in turn crowded out by more efficient animals or until it succumbed to other adverse factors in its environment.

Have we any reason to suppose that *Homo sapiens* is not subject to the same process or that his fate will not be similar? He differed from earlier species of men very slightly in physical form and structure. His achievements and the shapes of his crania suggest that he possessed, from the outset, not only a larger but probably also a distinctly better brain, which has enabled him to learn more extensively, to devise complicated languages, and eventually to develop what we now call civilization. This progress seems to have gone forward on a steadily rising curve. For perhaps 20,000 years *Homo sapiens* was only a savage, a wandering hunter. In the next 5000 years or more he advanced locally to the status of a shepherd and even a village farmer. In another 3000 years he learned to extract and use metals, form city states and even nations, and become skillful in many of the finer arts. Accelerated advance in the next 1000 years lead to books, commerce, literature, and philosophy. The last century or two has witnessed a rapidity of material progress in communication and far-flung organization that exceeds anything previously known; and with it has come much growth in ideas and in the complexity of economic and social arrangements. Are we justified in assuming from the contemplation of that curve that it will continue to rise indefinitely, and at a similar rate? Is there in all geologic or human history any precedent for that? Other animal species of the past have followed career curves that involved a rise, culmination, and decline. We have seen the same law controlling the nations and even races of Humanity. Will our own species also reach its climax and then deteriorate? And if that happens, how and when will it occur? As yet we have but little basis for answers to such questions.

In contrast to his progress in ways and ideas, *Homo sapiens* seems to have undergone only slight physical changes, even in the estimated 30,000 years of which some records have come down to us. Anatomically

there seems to be no evidence whatever of any progress—no increase in cranial capacity, probably no appreciable change in brain anatomy. In the last 3000 years, in which some evidence is available, there is no sign of any improvement in native intelligence. Man's actions are still governed more by his emotions and subconscious mental elements than by his intellect. His savage instincts, that we like to think began to be conquered thousands of years ago, are still present beneath the surface and reappear at unexpected intervals even in civilized man. Among the more backward modern races of Humanity they have scarcely changed.

In short, our surviving species of Homo, being one of the mammals, is probably as definitely limited in his possibilities as are the other species of that class. Just as we do not expect a dog to learn algebra, although he can learn to open a door, so we probably ought not to expect more from present-day Man than his brain is capable of attaining. As Hawkins (1930), the English paleontologist, sees it: "Our mental capacity is a specific character." If this is the truth of the matter, it may be over-optimistic to expect our own species to rise far above his present stage of mentality. Notable improvement along lines already established, and a raising of the other two-thirds of the Earth's population to or above the level of the present civilized minority, may well take place over the centuries and thousands of years yet remaining in the expectable future life of this species. His contribution to biological progress will then have been made, and, if History is to repeat itself, he will then be ready for conquest, if not extermination, by some other type of being, perhaps some new species of the Hominidae that has more innate capacity for progress.

Whence may such a higher species originate? Will it be an outgrowth of the most highly civilized nations of today? The general testimony of History suggests the contrary. The ancestral mammals did not spring from the most advanced dinosaurs of the Mesozoic era. Man and the great apes are traced back, not to the large specialized mammals of Eocene times, but to primitive generalized animals related to the humble insectivores. The extraordinarily successful Mongol dynasty of the Middle Ages arose not from the cultivated Chinese of Nanking, but from a tribe of barbaric nomads of the steppes. Likewise the most civilized nations of modern Europe did not spring from the Romans of Caesar's day but from the forest barbarians around the Baltic. Perhaps, therefore, the progenitors of the newer and better Man will appear unnoticed in some remote and backward corner of the world, where they can develop in obscurity, while the well known modern races of *Homo sapiens* contend with each other for a transient supremacy.

Just as it would have been difficult for even a most intelligent trilobite to imagine the fish, which was destined to drive him from the scene, so it is not easy for us to forecast the nature and potentialities of that new species of *Homo* which may appear in the distant future, unless indeed our genus itself has by that time run its course and is not destined to offer the world anything further. It is of little consequence whether such a new species may have smaller teeth, a skin less hairy, or taller stature. The only way in which he is likely to outstrip *Homo sapiens* effectively is in the quality of his brain. Will he be able to absorb knowledge more rapidly and remember it better? Will his imagination be keener; will he reason out his problems more effectively; and, above all, will his life and conduct be controlled by his intellect rather than by his feelings? If so, he may be able to take knowledge in larger doses, profit more by the stored-up experience of others, instead of merely his own, and by the lessons of history. He should be far more educable than any earlier species in the family.

It may be objected that these speculations are hardly optimistic, that they do not present a hopeful picture, and that they do not necessarily envisage continued progress toward a far higher and better human world. To this I must reply that a scientist is under no obligation to be an optimist. His only concern must be to approach nearer to the truth. If the truth offers hope, we may all rejoice. If it fails to do so, we are not thereby justified in denying or even ignoring it. As King Solomon long ago advised, let us get understanding, and by so doing we may reach a serenity of outlook that will fit us better to play a worthy part in the great drama of human evolution.

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PERMIAN FAUNAS: A STUDY IN FACIES

BY CARL O. DUNBAR

(*Address as Retiring President of the Paleontological Society*)

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INTRODUCTION

Approximately 140 years ago William Smith discovered the use of fossils in correlation. Most of his life had been spent as a surveyor

crossing and recrossing the Jurassic rocks of England where the structure is simple and many of the formations are easily identified by lithology. Distinctive beds can be traced along the outcrop from quarry to quarry where Smith was wont to hunt fossils, and thus he came to realize that each formation has distinctive species by which it can be identified without the trouble of tracing.

It is no accident that within the half century following Smith's discovery the entire geologic column was securely established and all the systems were correctly identified, not merely in England but across the whole of Europe and eastern North America, for no other conception has ever become such an open sesame to the secrets of Earth's history. Without it we should still have no general time scale, and correlations of the younger rocks would even now be as uncertain as those of the pre-Cambrian.

But the use of fossils is by no means as simple as William Smith then believed. Perhaps the greatest obstacle—not suspected by Smith, and still not appreciated by some stratigraphers in high places—is the influence of changing facies.

In his address before the Geological Society a year ago, President Vaughan analyzed the ecology of modern marine organisms, seeking criteria by which to reconstruct the physical and chemical conditions prevalent in the seas of the past. He showed how both animals and plants are limited by depth, currents, sunlight, chemical features of the water, and physical character of the sea floor. As a result of such factors, faunal assemblages, largely distinct, live side by side, each restricted to some special environment. Doctor Vaughan focused attention on the paleogeographic significance of these facts and strove to lay a firmer basis for interpreting the records made by the ancient seas. It is proposed here to discuss another aspect of the picture, namely the difficulties that such faunal restrictions present in stratigraphic correlation.

The subject of facies change is not novel. Within 40 years after Smith had discovered that he could correlate the Jurassic rocks across England by fossils, Gressly had found that in Switzerland some of the Jurassic horizons change character along the strike, both in lithology and in faunas. For these distinct aspects of each horizon, based on either lithologic or biologic characters, he introduced the term *facies*. Moreover, he found the same facies locally in different horizons and thus foresaw clearly the difficulties involved in using fossils for accurate correlation. Mojsisovics encountered the same difficulties in the Tirolean Alps in 1879, and most subsequent students of alpine geology have appreciated the significance of facies, as shown by Diener in 1925 and by Pia in 1930.

In America there is a large and growing school of stratigraphers who recognize the bearing of facies on stratigraphic interpretation, but a few conspicuous figures still ignore the conception or fail to see its implications in actual practice.

Such changes of facies occur in every geologic system but perhaps nowhere on a scale more impressive than in the Permian. I have chosen to use the Permian as a basis for discussion partly from personal interest and partly because it provides instances of lateral change so abrupt and so profound as to be easily demonstrated and analyzed To discuss the problem here at Austin is, of course, like carrying coals to Newcastle, for the Permian rocks of Texas display changes of facies hardly exceeded elsewhere in the world, and the men working in this region have contributed greatly to the understanding of such relations. Nevertheless, little more than a start has been made in the critical analysis of particular facies faunas, and there is still much to be done. The data for such study must be gathered in the field, not in the laboratory; and the purpose of the present discourse is to emphasize their importance and to encourage their study.

LATERAL CHANGE FROM MARINE TO NONMARINE FACIES

THE KAZANIAN SERIES OF THE RUSSIAN PLATFORM

The most obvious change in the *biologic* facies is seen where marine deposits grade laterally into nonmarine. A magnificent illustration was studied by members of the Permian excursion of the Seventeenth International Geological Congress when we followed the Kazanian horizon from the city of Perm across the Russian Platform to Kazan. In this 300-mile stretch (Fig. 1), the nearly horizontal Kazanian beds are more or less continuously exposed in the bluffs of the Kama River, which rise at many places from 100 to 200 feet above the valley floor.

About Perm this series is represented by bright red, unfossiliferous sandstone and siltstone some 500 feet thick. This is the nonmarine, Ufimian facies, so called for the city of Ufa which is on the strike south of Perm. In conspicuous contrast, the equivalent beds in the environs of Kazan are richly fossiliferous white limestone. Our 3-day journey by steamer down the Kama, stopping repeatedly to examine and collect, gave us ample opportunity to observe the gradual change in lithology.

For the first several hours below Perm the bluffs were monotonously red, and then gray lenses of channel sands were seen in increasing numbers. We stopped to examine one of these at Babka and another at Saigatka, finding in both the leaves of a large fern, *Odontopteris*, and petrified driftwood. At near-by Ischajewo, stegocephalians and reptiles (*Ulemo-*

saurus, Titanophoneus, Moschops) have been found and recently were described by Efremov. During the second day's journey we saw tongues of gray siltstone and shale within the red beds, increasing in number and thickness toward the west. At Tikhye Gori we found in one of these gray

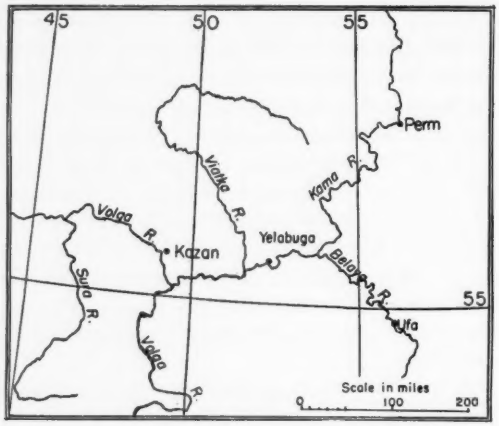

FIGURE 1.—*Sketch map of part of the Russian Platform*

tongues the first elements of a marine fauna—a few cypriid ostracods, small clams, and rare specimens of a small spiriferoid brachiopod. Associated layers yielded fossil insects and fragments of land plants. At Yelabuga thin beds of oölitic limestone were added to the section, and the marine fauna was somewhat more varied; and by the time we had reached Vandovka, some 80 miles east of Kazan, the bluffs appeared more gray than red, and three distinct tongues of impure limestone were observed. The limestones increased rapidly toward the west, and fossils became more abundant and more varied at successive stops. Thus, in a journey of some 300 miles, we saw the lateral transition from the deep red, unfossiliferous sandstones at Perm into the white limestones at Kazan, a transition marked by deep intertonguing of marine and nonmarine zones.

The Kazanian faunas occurring along this route have been monographed by Netschaeva, who records 180 species in the environs of Kazan. Even here the fauna is somewhat restricted in its scope, having no fusulines and no ammonites and very few corals or echinoderms; but it does include 10 species of bryozoans, 27 of brachiopods, and lesser numbers of several other groups, in addition to a large number of pelecypods. In contrast

to this, the marine tongues exposed about Yelabuga and from there to the east yielded only 31 marine invertebrates. These included 1 species of Foraminifera, 1 of sponges, 3 of worms, 1 linguloid and 4 articulate brachiopods, 2 gastropods, 1 nautiloid, 1 brachiopod, 3 ostracods, and 14 small clams.

An analysis of the changing faunas indicates that the marine tongues which reach so far east into the Ufimian red beds represent more and more brackish water toward the east until finally they grade over into fresh-water deposits. With this gradual change two things happen to the fauna. The first is a screening out of more and more of the species until there are left a few of the most hardy, the most ubiquitous, and therefore probably the longest-ranging forms. Toward the eastern limit of these tongues there is progressive reduction of the number of species and a dwarfing of those that persist, a phenomenon also observed by Goldring in her study of the postglacial faunas of the Champlain embayment. A second change involves the addition to the fauna of brackish-water elements, such as *Estheria* and *Liebea*, and fresh-water or terrestrial forms, such as insects and land plants. The net result is that, in tongues reaching far out in the nonmarine facies, the faunas are limited in variety, they lack most of the diagnostic elements of the equivalent marine deposits, the species present are in part ubiquitous and long-ranging and therefore of limited value in detailed correlation, and they contain elements of unknown value which are not represented in the standard marine sequence.

EXAMPLES FROM THE AMERICAN PERMIAN

The Phosphoria formation in Wyoming presents a close parallel to the Kazanian relations just described, but the exposures there are less favorable. Thomas has succeeded in tracing several tongues of the Phosphoria limestone eastward into the Chugwater red beds, as represented in Figure 2. The Sybille tongue has now been identified as the Minnekahta limestone in the rim of the Black Hills. There, it is for the most part strangely barren of fossils, but abundant small clams occur locally near its base. These have been known and collected by a number of paleontologists, but in the present state of our knowledge they do not justify correlation with other formations, nor do they indicate clearly whether the beds are Pennsylvanian or Permian.

A comparable fauna of small clams occurs locally in dolomite beds in the Blaine group of central Oklahoma. For the most part this is a red-bed and gypsum-bearing group of strata now correlated on the basis of physical stratigraphy with the upper part of the Leonard series of Texas. The Leonard faunas are large and varied, including fusulines,

ammonites, and brachiopods, but the few fossiliferous tongues that extend into the Blaine of Oklahoma carry only a few "nondescript" little clams.

The fauna of the Whitehorse sandstone of west-central Oklahoma and the panhandle of Texas illustrates again the influence of environment

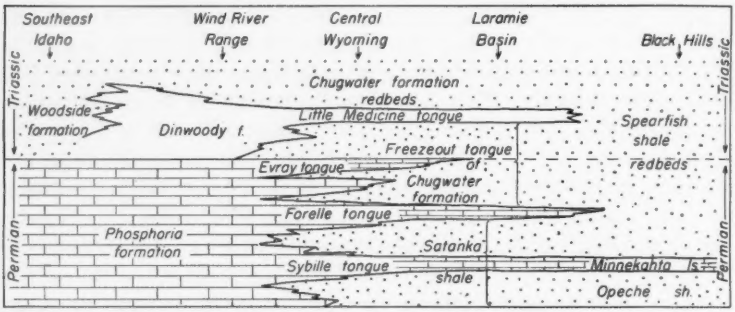

FIGURE 2.—*Idealized stratigraphic section showing the relation of the Phosphoria formation and its red-bed equivalents in Wyoming*

Slightly modified from Horace D. Thomas.

on a marine assemblage. Newell's recent study has confirmed the belief that the Whitehorse sandstone is equivalent to the Capitan horizon of the Guadalupe region. For the most part the Whitehorse group is made of red beds, presumably nonmarine; but a few thin lenses of calcareous beds carry a limited marine fauna. Newell records 32 species, of which 26 are pelecypods and small gastropods, most of them unknown elsewhere. Of bryozoans there is a single species and of brachiopods 4, none of them common. The contemporaneous marine fauna of the Delaware Basin, on the contrary, is large and varied, with ammonites, fusulines, and abundant brachiopods.

Even though intertonguing of beds or the presence of identical species may prove the correct correlations, there is more *general resemblance* among the faunas of the Minnekahta limestone, the Blaine gypsum, the Whitehorse sandstone, and the Ufimian beds of Russia than there is between any one of these and its nearest, normally marine equivalent!

VERTICAL CHANGES FROM MARINE TO NONMARINE

TYPE SECTION OF THE PERMIAN SYSTEM

Thus far we have considered only the lateral changes of facies due to local inequalities in the environment at a given time. But there are also instances in which the environment over a large area changed

gradually from marine to nonmarine conditions during a considerable lapse of geologic time. An illustration is afforded by the Permian section in Kansas and Nebraska, where the basal part (Council Grove group) is mostly marine and has a varied fauna, while the upper part is entirely nonmarine and consists of unfossiliferous red beds. If studied in ascending order, the faunas of successive formations show an irregular but progressive change, comparable to the lateral change displayed in the Kazanian faunas. The Council Grove group of Kansas, for example, is marine and generally fossiliferous, but the succeeding Chase group includes alternating fossiliferous and barren formations in which the higher marine faunas are progressively more limited in scope and eventually consist largely of small pelecypods.

The type section of the Permian system, unfortunately, presents such a change in facies, as shown in Figure 3. The Sakmarian and Artinskian horizons are largely marine and richly fossiliferous; but the Kungurian, with its vast salt deposits, has very limited faunas; the Kazanian series marks a return of marine waters over the western part of the Russian Platform, but even this fauna is limited in facies, having no fusulines and no ammonites and but few of the distinctly Permian genera of brachiopods; the Tartarian includes only nonmarine red beds with land plants and fossil reptiles and stegocephalians. In short, the lower part of the section is normally marine and carries an immense fauna including ammonites, fusulines, a great variety of brachiopods, mollusks, corals, and bryozoans, but the middle part has much restricted and only partly normally marine faunas, and the upper part is wholly nonmarine.

In spite of its historical importance, therefore, this is a poor standard for international correlation, just because so much of it is nonmarine. Murchison originally included only the Kungurian, Kazanian, and Tartarian, basing his system largely on the evidence of fossil reptiles and plants and referring the underlying normally marine beds (Artinskian and Sakmarian) to the Carboniferous. The *original* Permian thus contains but few distinctive genera of brachiopods and no fusulines or ammonites. It was Karpinsky who added the Artinsk to the Permian because his analysis of its ammonite fauna showed closer relation to the Permian than to the Carboniferous. This may sound strange in view of the fact that the original Permian has never to this day yielded a single ammonite! But by 1889, when Karpinsky made his study, the Trogkofel limestone of the Carnic Alps, the Sosio beds at Palermo, the *Productus* limestone of the Salt Range, and other marine formations had come to be recognized as Permian, and on the basis of these faunas, outside of Russia, Karpinsky revised the original Permian in its type region.

OBSTACLES TO CORRELATION, EXEMPLIFIED BY THE PERMIAN OF EAST GREENLAND

The practical bearing of these facts on correlation with other regions is illustrated by recent studies of the Permian faunas of East Greenland.

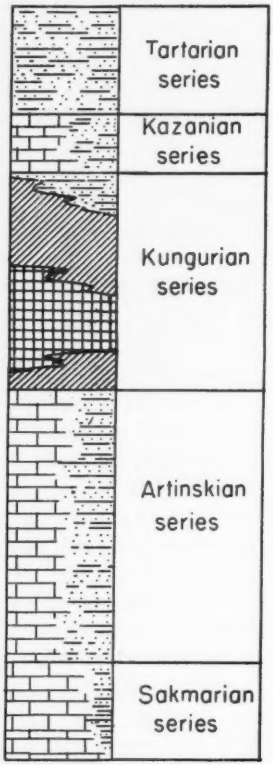

FIGURE 3.—*Generalized columnar section of the type Permian of Russia*

The Kungurian includes vast thicknesses of anhydrite (oblique shading) and salt (quadrille shading).

Large collections have been made there by Lauge Koch and his assistants, who recognize two quite distinct marine facies, one of limestone rich in brachiopods and bryozoans and the other of shales bearing clams and rare

ammonites (Fig. 4). Recognizing that these faunas belonged to the Russian province, Frebold correlated the Brachiopod limestone of East Greenland with the "Schwagerinakalk" of the Ufa Plateau, and the ammonite-bearing shales with the Artinsk of the Urals. This was but natural, for the general resemblances between the beds thus correlated

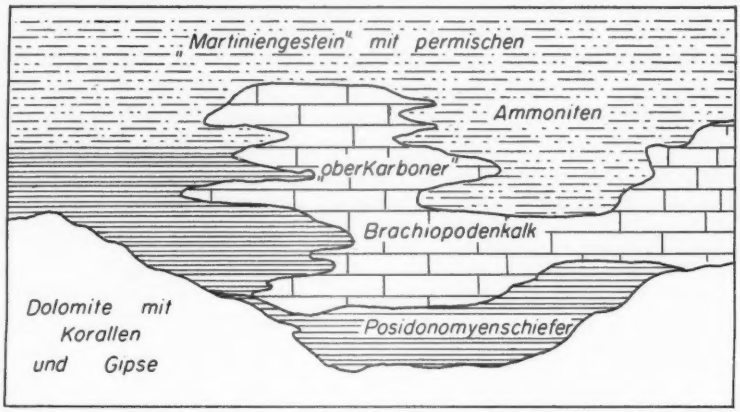

FIGURE 4.—*Idealized stratigraphic diagram showing the relations of lithologic facies in the Permian of East Greenland according to Hans Frebold*

are striking. But in both he was correlating facies with like facies. The fact remains that we do not know a typical marine brachiopod fauna of Kungurian, Kazanian, or Tartarian age in European Russia, and there is little basis for a direct comparison of the Greenland beds with that part of the type section of the Permian.

Fossil fishes from the Posidonomya shales have been monographed by Nielsen and Aldinger, and the latter (1935) has reviewed the evidence of this group and pointed out close resemblances and possibly identical species in the fish faunas of the Zechstein of Germany, the Phosphoria of North America, and the Kazanian of Russia. Furthermore, restudy of the ammonite *Gothabites* from the Martinia shales of Greenland has convinced A. K. Miller (personal communication) that it is approximately at the cyclolobine stage of evolution and should be high instead of low in the Permian. It appears necessary, therefore, to restudy the brachiopods of Greenland critically and to compare them with the higher marine faunas of other parts of the world as well as with the basal part of the type Permian.

LATERAL CHANGES OF FACIES WITHIN A MARINE PROVINCE

MODERN EXAMPLES

Modern studies of marine ecology have presented striking illustrations of the extent to which bottom faunas are limited by the physical character of the sea floor. Two instances may be cited by way of illustration.

Near the famous marine biological station at Naples there is a tiny shoal, known as Pigeon Bank, standing about 115 feet above the adjacent muddy floor of the bay. On the bank Walther found 296 species of shell-bearing animals (*i. e.*, those capable of fossilization), whereas but 31 were found on the adjacent muddy bottoms. Moreover, only 14 species were found to share the two environments. If these two types of sediments were preserved as limestone and shale, respectively, their faunas would have but little in common in spite of the fact that they accumulated side by side. Surely our Paleozoic record is full of instances of this sort.

A striking case of a different nature is that of Great Bahama Bank, one of the largest areas of modern limy deposits (Fig. 5). With an area of nearly 7000 square miles, it presents a remarkably flat surface over which the water is mostly less than 20 feet deep. Andros Island rises as a low rim along its eastern margin, and the bank stands as a great limy platform with steep slopes, rising out of deep water. About 5000 square miles of its surface, west of Andros Island, has a bottom composed of fine limy mud. During storms this sediment is partly lifted into suspension, making the water turbid and milky, but with the return of fair weather it settles back like a fall of fine snow, smothering and killing nearly all kinds of sessile bottom life. As a result, the fauna of the mud-covered area is amazingly limited for a shallow limy sea floor in a subtropical region. The chief animals of the mud-covered area are crustaceans, notably *Crangon,* a form that burrows in during storms and digs out afterward. Corals are lacking, and marine mollusks are rare and of few kinds; and by a strange vagary of Nature the commonest shells are those of *land* snails which live in abundance on Andros Island and are washed or blown into the sea.

During storms, the sediment in suspension is partly carried beyond the edge of the bank where it settles over the steep marginal slope, reaching as far out as the center of Florida Strait. Parts of the bank have a solid floor of somewhat older limy deposit, where the currents prevent the present lime-mud from coming to rest. In these areas a more normal and varied benthonic fauna exists.

CAPITAN REEF AND RELATED FACIES

The water is now so shallow over Bahama Bank that probably little of the sediment comes to rest there permanently, but if slow subsidence

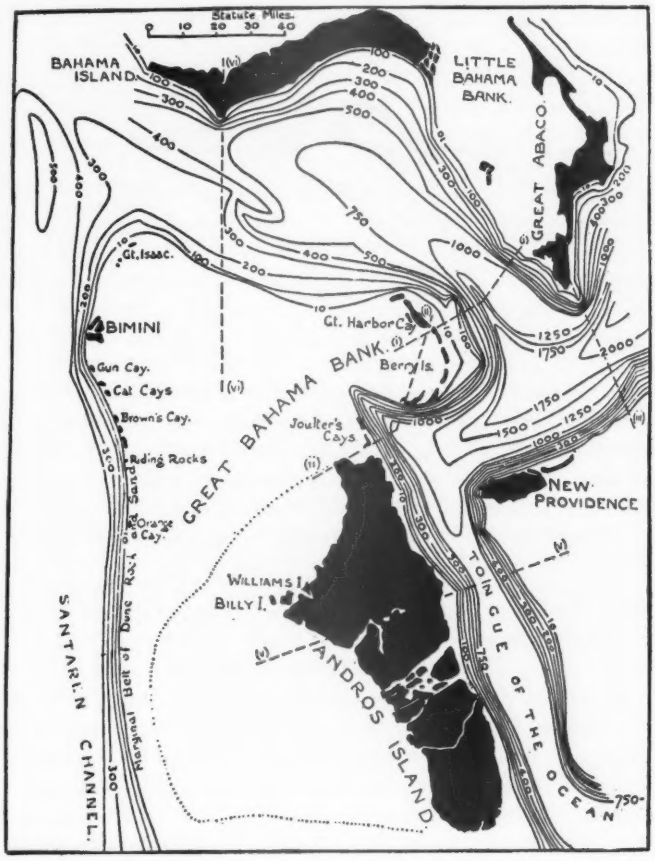

FIGURE 5.—*Map of Andros Island (black) and a part of Great Bahama Bank*
Showing the area of thick lime mud (within dotted line) west of Andros Island. After R. M. Field.

were going on, a limy deposit would form having many of the features of the great Permian "reefs". Such limestone masses as the Capitan reef, for example, clearly stood well above the surrounding sea floor (Fig. 6).

The massive deposits of the reef proper are for the most part strangely unfossiliferous, though fossils occur abundantly in spots and at certain levels; but the biostromes that descend from its seaward margin into the Delaware Basin are richly fossiliferous, as is the well-bedded Carlsbad limestone on the lagoonal side of the reef. Probably the scarcity of

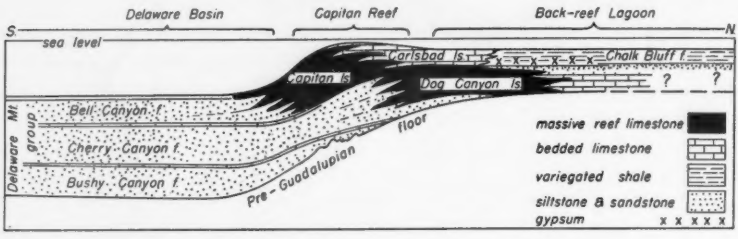

FIGURE 6.—*Diagrammatic section across the Capitan reef*
To show relations of the reef (black) to related facies. Adapted from Walter B. Lang.

fossils in the massive core of the reef is due to the fact that the bottom there was inhospitable to benthonic animals. A fascinating problem still awaiting critical study in connection with such great Permian reefs is the actual distribution of fossil organisms in different parts of the reef and in the adjacent and contemporaneous deposits of other facies. The Capitan exposures afford an unusual opportunity for such study.

THE ARTINSK AND ITS LIMESTONE EQUIVALENTS

The troublesome problem of the Pennsylvanian-Permian boundary arose largely because of changes of facies in the type region of the Permian. When Karpinsky added the Artinskian to the Permian in 1889, his arguments were generally accepted, and the typical Artinsk has been placed in the Permian by practically all subsequent students, including the Geological Survey of Russia. The typical Artinskian is a detrital facies of sandstones, siltstones, and shale with interbedded conglomerate, distributed in a rather narrow belt along the western flank of the Urals. It bears an extensive fauna from which Krotow was able to identify 293 species, but the fossils are largely restricted to certain zones interbedded with barren shales or sandstones. Conspicuous among its fossils are the ammonites, which Karpinsky proved to tie in with Permian faunas of other regions.

To the west of the Artinskian facies, however, lies the Ufa Plateau, presenting a great thickness of limestones, in part well bedded and in part reefy. These also contain a very large fauna, chiefly of brachiopods,

bryozoans, fusulines, and corals. The brachiopods mostly belong to "Carboniferous genera", and the limestones which carry them were referred to the Carboniferous by Murchison. Moreover, when Tschernyschew monographed the brachiopods in 1902, he assumed the beds to be Upper Carboniferous, and this was adopted as the official usage of the Geological Survey. Only within the last decade or so has it been discovered that the "Upper Carboniferous" limestones of the Ufa Plateau and the Artinskian detritals farther east are only distinct facies and that they are largely equivalent in age. The stratigraphic relations are obscured in this instance by the scarcity of exposures in the transition zone where intertonguing should provide a certain clue. The evidence for equivalence rests in part on regional stratigraphic relations and in part on the presence of zone fossils not restricted to either facies. Such, for example, are the shark, *Helicoprion bessonowi*, found in the Artinsk facies on Sylva River and in the limestone facies at Upper Tschussovaya village; or the Artinskian types of ammonites recently found in the Shikhans near Sterlitamak; or the fusulines also recently found in the lower part of the Artinsk facies about Sim Works.

Even within the limestone facies of the Ufa Plateau there are striking restrictions of the faunas, recently described by Tolstikhina. She recognizes four distinct stratigraphic horizons, each divisible locally into several organic-lithologic facies. For example, she finds that the Jurezan horizon includes a bryozoan reef facies, a hydroid reef facies, and a facies of well-bedded limestone with corals and fusulines; and the succeeding Chernaia Rechka horizon includes coralline-algal reefs grading laterally into stratified limestone with brachiopods and fusulines.

DISTINCT PROVINCIAL FACIES

MODERN EXAMPLES

The existence of well-defined faunal provinces in the modern oceans is well known. In some instances the faunal distinctness is apparently due largely to isolation, as by a land barrier. For example, Dall found on the Pacific side of the Isthmus of Panama a fauna of 805 species of shell-bearing invertebrates and on the Caribbean side 517 species, yet only 24 of these are common to the two regions.

Such distinct faunal provinces may also be caused by differences in temperature in a continuous shelf sea. For example, Dall recorded a fauna of 180 species of shell-bearing mollusks off the coast of Greenland, 277 in the Gulf of Maine, 305 off the Carolina coast, 681 off the west coast of Florida, and 517 along the coast of Panama. The total of these figures is 1960 and by actual count there are 1772 species involved. In

other words, less than 200 species out of 1772 have appeared in two or more of the provinces mentioned, and the overwhelming majority of them are restricted to a single province. Here temperature appears to be the most important limiting factor.

Differences in salinity obviously account for the contrast between the fauna of the Baltic and that along the west coast of Norway.

There are, however, some faunal restrictions in the modern oceans for which no simple explanation is apparent. The majority of shallow-water articulate brachiopod species now living are confined to the Australian region, and most of the living crinoids are confined to the Indian Ocean. Each of the other oceans presents an equal range of environments but almost lacks representatives of these two great stocks.

Now, whatever the cause of such restrictions, it is evident that epeiric seas derived from two distinct faunal provinces may have little in common, or at least may show striking differences in their faunas.

CONTRAST BETWEEN THE LEONARD AND KAIBAB FAUNAS

An illustration from the Permian is that of the contrast between the Leonard and the Kaibab faunas, which are known to be contemporaneous but which represent two embayments, more or less completely separated (Fig. 7). The Leonard faunas contain abundant fusulines, many ammonites, and such distinctive Permian brachiopod genera as *Leptodus, Prorichthofenia, Geyerella, Aulosteges, Scacchinella,* and *Waagenoconcha* (King described 30 genera and 81 species of brachiopods); the Kaibab, on the contrary, has never yielded a fusuline or an ammonite, and, with the exception of a rare species of *Waagenoconcha,* its brachiopods are all of long-ranging Carboniferous genera. (McKee records 15 genera and 22 species of which all but two genera occur in the Pennsylvanian.) There is little about the Kaibab fauna to indicate a Permian rather than a Pennsylvanian age, except the presence of zone species, such as *Dictyoclostus bassi,* which are identical with those in the Leonard. For some reason, not understood, the distinctive elements of the Permian faunas largely failed to exist in the Kaibab sea.

COMPARISON OF WORD AND PHOSPHORIA FAUNAS

The Phosphoria formation of Utah and Wyoming is probably equivalent to part, at least, of the Word formation of Texas. Both are marine, and each has a fairly extensive fauna, yet there are few species in common, and the general composition of the Word fauna is quite different from that of the Phosphoria. The Word has abundant ammonites and fusulines, and its brachiopods include such characteristic Permian genera as

Waagenoconcha, Aulosteges, Prorichthofenia, and *Leptodus,* whereas the Phosphoria has thus far yielded no fusulines, only three genera of ammonites, and none of the last three brachiopod genera. Nevertheless, according to R. E. King, at least seven species of the Phosphoria

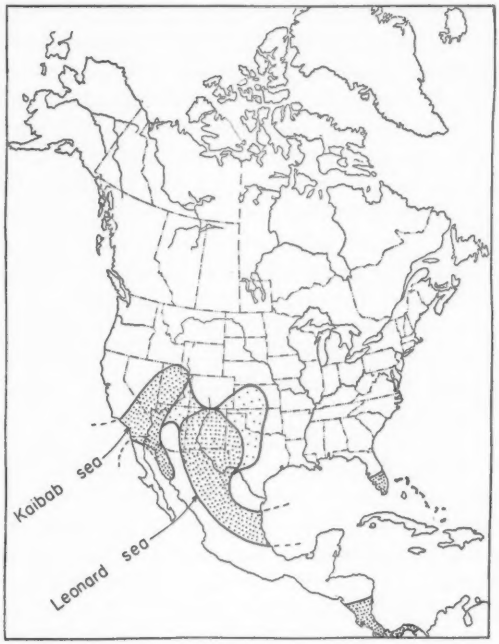

FIGURE 7.—*Paleogeographic map showing inferred relations of the Leonard and Kaibab seas*

Normally marine areas are closely stippled and nonmarine or abnormally marine parts of the basin are sparsely stippled. After Charles Schuchert.

brachiopods occur also in the Word. The ammonite species are believed by Miller and Cline to be of Word age, but none are quite identical with forms from Texas. If the Word and Phosphoria seas were contemporaneous, they were only indirectly connected, or else some conditions in the Phosphoria sea prevented most of the Word fauna from entering. The phosphate deposits suggest that chemical conditions may have been abnormal during at least a part of the time when the Phosphoria deposits were forming.

THE ECHINODERM FAUNAS OF THE PERMIAN OF TIMOR

One of the most amazing local peculiarities known among Permian faunas occurs in the Island of Timor in the Netherlands East Indies, whence a blastoid fauna of 14 genera and 32 species and varieties was described by Wanner. With this exception, no blastoids are known in any part of the world in rocks younger than the Lower Carboniferous. All the species and all but two of the genera of Timor are distinct from Lower Carboniferous types, and the extreme specialization of some of the genera reflects their younger age. There is likewise a large and specialized crinoid fauna in the Permian of Timor, from which Wanner originally described 28 new genera and 105 new species out of a total fauna of 44 genera and 123 species. After later expeditions Wanner (1924) indicated that a total of 75 genera and 239 species of crinoids could be recognized.

Most of the crinoids and all the blastoids are limited, so far as now known, to Timor. This appears the more remarkable because the abundant representatives of other groups, such as ammonites, bryozoans, and brachiopods, do not display a marked provincial character. Most of the ammonite species are local, but the genera are widespread in other parts of the world and permit satisfactory interregional correlation. The brachiopods and bryozoans, likewise, show no more than local specific distinction from contemporaneous faunas in Europe, Asia, and America.

As yet there is no evidence as to the nature of the environmental factors that gave asylum here to the blastoids and produced such a burst of evolution in both blastoids and crinoids, at the same time preventing the migration of all the blastoids and most of the crinoids to other parts of the world. It can hardly have been a physical barrier, since other groups of animals show no evidence of such isolation. But the very existence of blastoids in the Permian of Timor is clear proof that they had an asylum somewhere throughout Upper Carboniferous time, and their appearance in faunas of that age should not be a great surprise.

THE ORIENTAL REALM AND ITS NEOSCHWAGERINE FAUNAS

One of the notable peculiarities of the Middle and Upper Permian of the Orient is the presence, commonly in great abundance, of fusulines of the subfamilies Neoschwagerininae and Verbeekininae. These characteristic faunas are found farther westward along the old Tethian geosyncline in Darwas, Afghanistan, Crimea, Greece, Sicily, and Tunis (Fig. 8). None of these has been found in the Salt Range of India or in Persia or in the Permian basin of Russia or in the Alps, and, with a local exception, they did not reach America. That exception must be made for the occurrence of neoschwagerines in a narrow belt extending from

near Kamloops, British Columbia, into Washington and Oregon. It seems to mark a western trough that was temporarily reached by the Oriental faunas. So far as the fusulines go, the neoschwagerines characterize a great faunal realm which, in Middle and Late Permian time, was

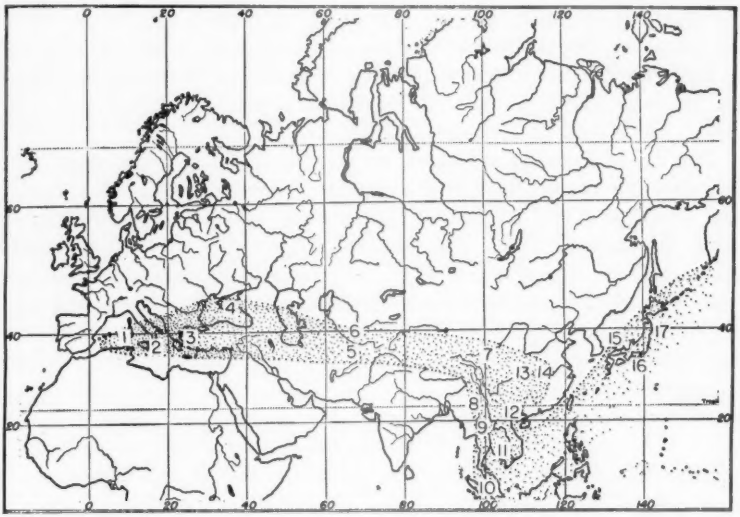

FIGURE 8.—*Map to show the extent of the seaway (stippled) in which the Neoschwagerine faunas of the Oriental realm flourished in Middle Permian time*

The numerals indicate significant fossil localities. 1, Tunisia; 2, Palermo, Italy; 3, Greece; 4, Crimea; 5, Afghanistan; 6, Darwas; 7, Mt. Omei, China; 8, northern Burma; 9, northern Siam; 10, Cambodia; 11, Tonkin; 12 and 13, Yangtze River, China; 14, Nagato, Japan; 15, Akasaka, Japan; 16, Kitakami Mountainland, Japan.

sharply isolated from the rest of the world. Nevertheless, other groups, such as the brachiopods and ammonites, do not indicate the same restrictions and seem to prove that the oriental fusulines were not limited in their distribution by land barriers alone.

CONCLUSIONS

We have focused attention thus far on the difficulties presented by changes of facies. The purpose has been to emphasize the fact that formations and faunas essentially different may be of the same age and that others, generally similar, may actually not be equivalent.

Time does not permit a development of the other side of the problem—namely, means of establishing correlation between contemporaneous facies

regardless of their differences. Some obvious aids are (1) the intertonguing of distinct facies as seen either in outcrop or in subsurface well records, (2) the presence in distinct facies of certain zone fossils not limited by bottom ecology or by other restrictions which affected the majority of the fauna, (3) the stage of evolution represented in progressively changing stocks, and (4) correlations through a third area where the faunas of two distinct provinces or facies mingle or intertongue.

The objective fact of contemporaneous but distinct facies will probably be generally admitted; but it is important to carry the conception into actual use in field problems in stratigraphy.

The illustrations reviewed now seem evident, yet scarcely more than 10 years ago the relations of the Capitan reef were not understood and the limestone facies of the Artinsk was still considered Carboniferous while the detrital facies was classified as Permian. Yet these cases, because of the very magnitude and abruptness of the facies changes, are relatively obvious. The earlier Paleozoic, especially that of the Appalachian trough, must be full of examples of changes in facies less spectacular and therefore less easily detected that still confuse our stratigraphic interpretations.

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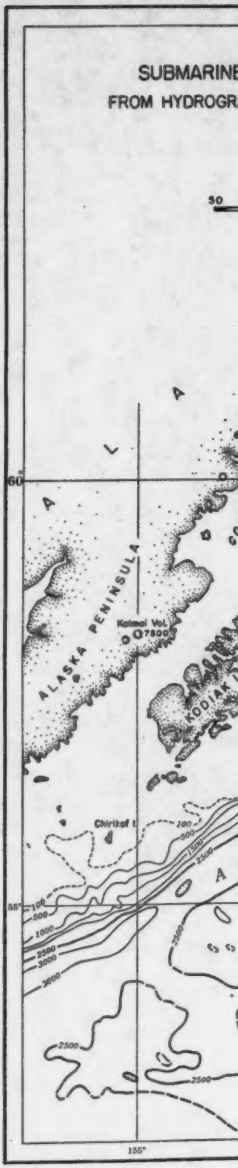
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SUBMARINE TOPOGRAPHY OF THE GULF OF ALASKA
OM HYDROGRAPHY BY THE U. S. COAST AND GEODETIC SURVEY
1925—1939

Contoured by Harold W. Murray
Contour Interval: 500 fathoms (3000 feet)

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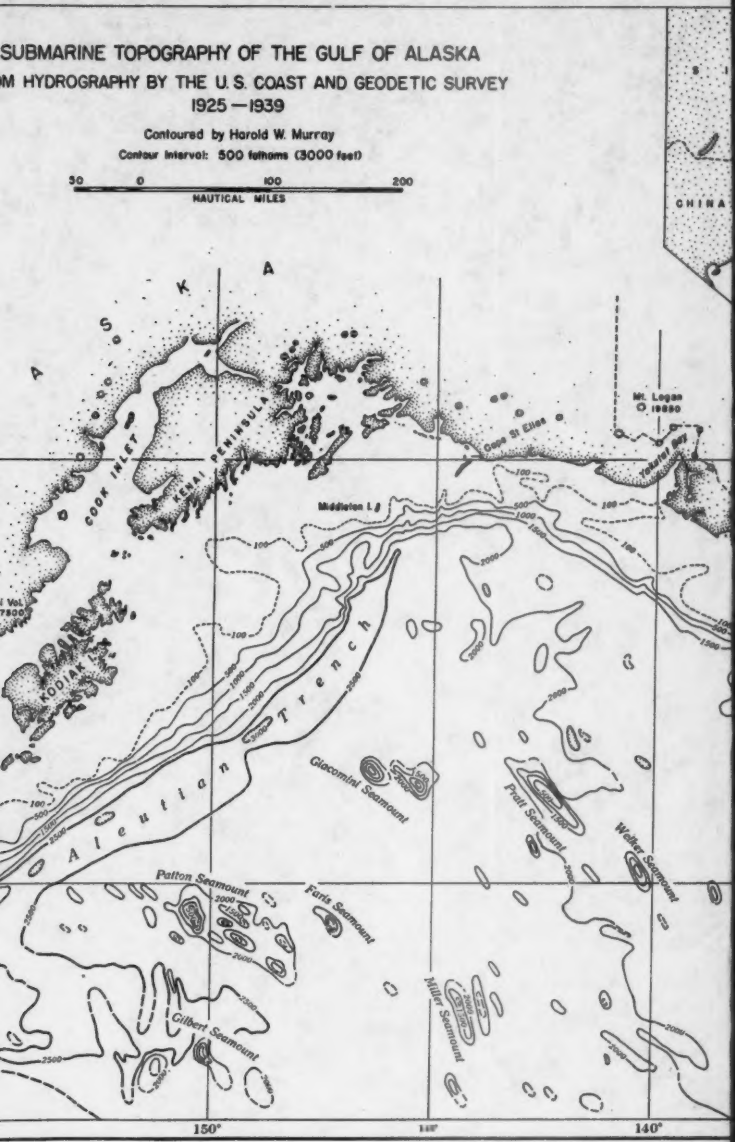

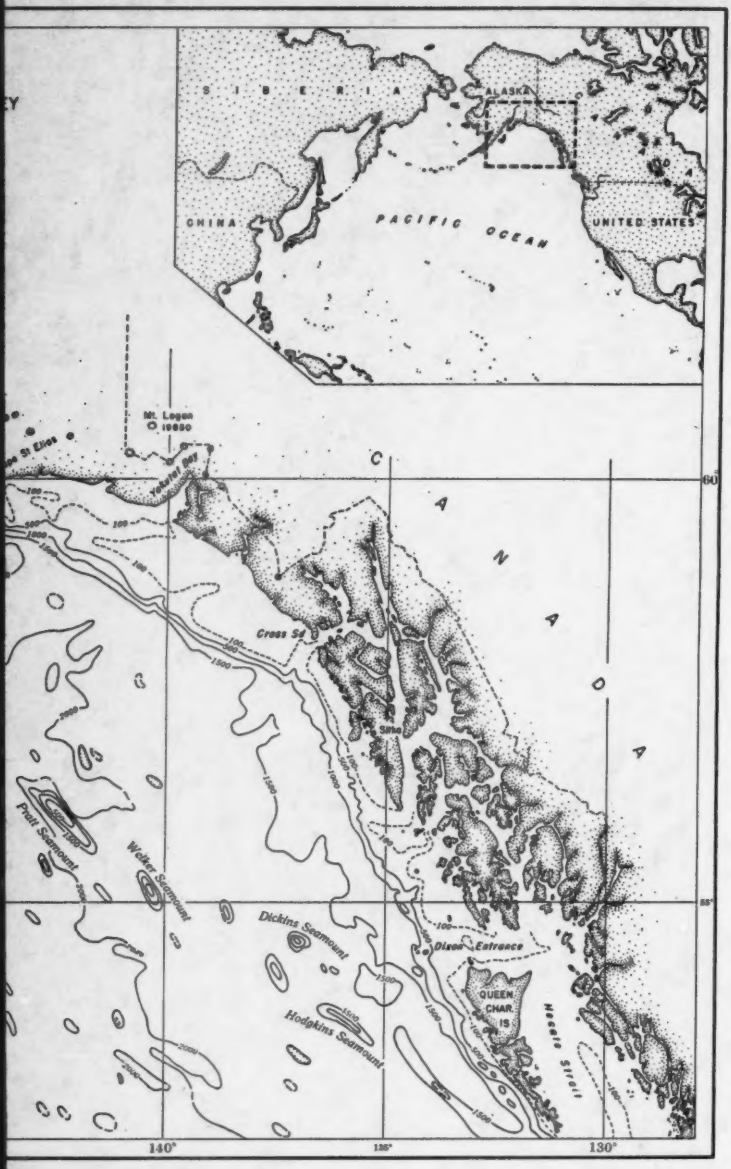

PHY OF THE GULF OF ALASKA

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SUBMARINE MOUNTAINS IN THE GULF OF ALASKA

BY HAROLD W. MURRAY

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Reconnaissance sounding lines in the Gulf of Alaska have revealed many submarine mountains rising sharply from 1 to 2 miles above the surrounding bottom. These mountains, as contoured, are approximately 10 to 25 miles wide and 15 to 70 miles long at the base. They occur singly and in groups, the groups tending to form ranges which extend northwestward across the gulf. Sections of all sounding lines indicating strong relief are reproduced in natural scale profile and show additional physiographic details not revealed by contours. The discussion accompanying the profiles is technical as well as descriptive in that it includes an evaluation of the sounding data. The utilization of the data with a view to postulating the origin of these submarine features is not within the scope of this paper.

INTRODUCTION

Echo sounding lines run by hydrographic agencies indicate that the floor of the Pacific Ocean between the Hawaiian Islands and the northwestern portion of North America has numerous submarine mountains or ranges which rise several thousand feet. Of particular interest are the groups of mountains recently discovered in the Gulf of Alaska which in some instances rise over 12,000 feet. From the standpoint of the physiographer problems of origin, shape, history, age, and relation to the Cordilleran border system on the American continent will be important. The seismologist has at hand definite, sizable features which may account for the presence of great earthquake tremors occurring in an area formerly believed to be practically devoid of relief. In addition these mountains form definite obstructions by which the oceanographer may partially account for the unusual currents encountered in this region with their corresponding effect on variation of temperatures and correlation with salinities at stated depths.

Continuous echo sounding across the Gulf of Alaska was begun by the United States Coast and Geodetic Survey in 1925. At the end of the 1939 season over 30,000 nautical miles of sounding lines had been run with a total of more than 36,000 recorded echo soundings. The arrangement of the lines is shown in Figure 1 where an area comprising over 200,000 square miles is now covered by sounding lines spaced about 25 to 30 miles apart. While this project is still far from completion, there is already available a wealth of sounding material in a formerly unknown area. This work was of a reconnaissance nature, carried out by vessels en route to and from their Alaskan working grounds. Many soundings were acquired but the astronomic control of these surveys cannot be compared with the more rigid control used in the coastal areas as described in Coast and Geodetic Survey literature (Hawley, 1928; Borden, 1938; Rudé, 1938). The soundings, however, are of standard accuracy for the depths encountered if consideration is given to the sounding instrument in use when the individual lines were run. The more im-

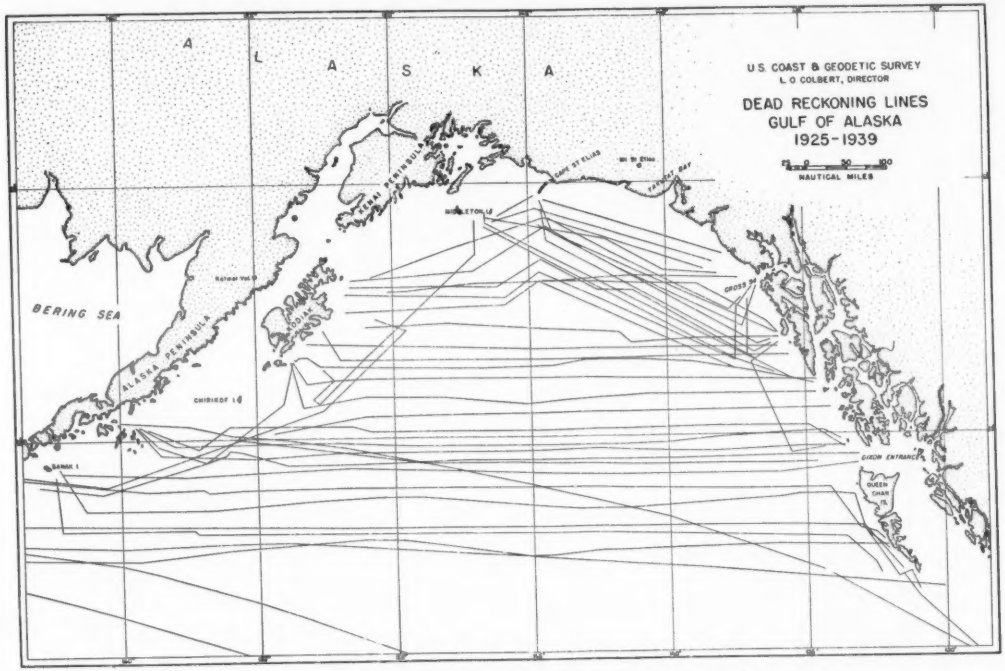


FIGURE 1.—*Dead reckoning lines across the Gulf of Alaska*
Showing courses followed by Survey vessels while obtaining soundings.

portant features delineated by these sounding lines are shown in the accompanying map (Pl. 1).

GENERAL FEATURES OF GULF

CONTINENTAL SHELF

A discussion of the submarine mountains should include a brief reference to associated features of the Gulf of Alaska. The continental shelf, contiguous to the coast line, has been developed by inshore surveys (Colbert, 1938). Its seaward limit here as in many other parts of the world is approximately defined by the 100-fathom curve. The width of the shelf varies as much as 100 nautical miles but is generally narrowest on the east side of the gulf and widest to the northwest. Near the southern tip of Queen Charlotte Islands the width is only about 1 mile but increases to about 35 miles just north of Dixon Entrance after which it decreases to about 12 miles south of Cross Sound. From Cross Sound to Cape St. Elias it has a width of 35 to 55 miles, widths of 75 to 100 miles are found off the Kenai and Alaska Peninsulas, but off Kodiak Island the shelf is only about 35 miles wide.

Portions of the 100-fathom curve indicate submarine depressions or valleys which completely cross the narrower shelf on the east but only indent the broader portion on the northeast, north, and northwest. The depressions in the latter areas rarely exceed 160 fathoms and are as much as 65 miles long and 30 miles wide. The depressions crossing the shelf on the east are somewhat deeper as depths of about 200 fathoms are quite common but cannot be carried continuously across the shelf. A characteristic usually accompanying these depressions is the greater depths found in the inland area; a maximum of 483 fathoms (2898 feet) exists in the fjord region on the east and 479 fathoms (2874 feet) in Prince William Sound on the north. Depths of about 190 fathoms are also found west of Kodiak Island. Shallow water, 10 to 65 fathoms, prevails in Cook Inlet.

Enclosed by the 100-fathom contour on the broad continental shelf to the north and northwest are a number of banks (Pl. 2) found at depths of 16 to 50 fathoms interspersed with occasional fingerlike depressions which have no outlets across the shelf. An unusual feature east of Prince of Wales Island is an oval-shaped depression (Fig. 2) which has been described by Heck (1927). The rim of this depression, lying at a depth of about 50 fathoms, is approximately 7500 feet wide and 12,000 feet long and is generally surrounded by higher ground. The bottom of the depression at a depth of 199 fathoms is about 150 fathoms or 900 feet below the rim.

CONTINENTAL SLOPE

The continental slope extending seaward from the 100-fathom contour is generally narrower on the east than on the northwest. Opposite Queen Charlotte Islands and between Cross Sound and Cape St. Elias, the

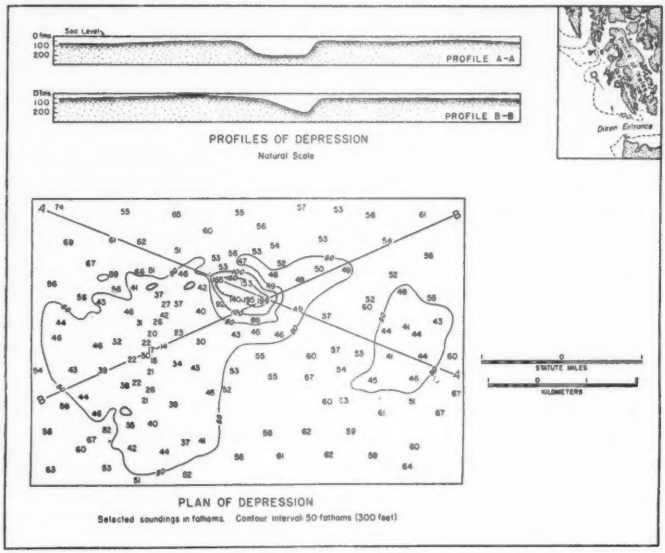


FIGURE 2.—*Submarine depression on continental shelf*
Off Prince of Wales Island.

width from the 100- to the 1500-fathom curve is about 10 to 25 miles with an approximate slope of 336 to 840 feet per nautical mile. From Dixon Entrance to Cross Sound the width between these curves is 40 to 85 miles with an approximate slope of 98 to 210 feet per mile. The great distance, 20 to 65 miles, between the 1000- and the 1500-fathom curves was possibly caused by delta deposits from former glaciers which deeply dissected the eastern mainland. Strictly speaking, the 1500-fathom curve in the eastern portion of the gulf does not necessarily define the base of the continental slope, but it has been selected for convenience because of the contour interval and its proximity to the lesser curves and their associated slopes. However, the distance between the 100- and 1000-fathom curves is fairly consistent, whereas the distance between the 1000- and 1500-fathom curves, while narrowest off Queen Charlotte Islands, becomes increasingly larger until about opposite Cross Sound

where it again narrows abruptly, conforming to the average width in the gulf region.

On the northwest the continental slope is exceptional, for it extends to the bottom of a deep trough and not to the principal floor of the gulf. The width from the 100-fathom curve to the bottom of the trough varies from 30 to 60 miles with an approximate slope of 580 to 1160 feet per nautical mile. Many submarine valleys are indicated on the continental slope, several lining up with the depressions on the shelf. The delineations in the deeper areas, however, are quite indefinite because of the wide spacing of the soundings.

SUBMERGED TROUGH

The submerged trough is better known as the Aleutian Trench or Foredeep since its deepest portion, 4000 to 4199 fathoms (24,000 to 25,194 feet), parallels and lies on the convex or south side of the arc of the Aleutian Islands (Pl. 1). The total length of the trough is at least 1700 miles, for it extends to the Attu Island at the western limit of the Aleutian Islands. The eastern extremity apparently terminates in two submarine valleys between Cape St. Elias and Yakutat Bay. The trough gradually deepens to the westward to more than 3000 fathoms where the bottom lies about half a mile below the rim on the seaward side. The greatest depths (Fig. 3) are generally found at the foot of the continental slope or 30 to 60 miles seaward from the 100-fathom curve. The slope of the trough on the seaward side is somewhat less than on the landward side.

FLOOR OF GULF

Broken by numerous high mountains and a long trough, the floor of the gulf is far from being level. The principal depth contours, however, generally parallel the continental slope except for a sharp convergence near Cape St. Elias. The re-entrants in the 1500- and 2000-fathom curves on the east, 20 to 90 miles long and 10 to 60 miles wide, are quite shallow in comparison to their horizontal dimensions. The floor of the gulf beginning at about 1800 fathoms (Fig. 3, Profile C-C) slopes concavely in a southwest direction to depths of about 2200 fathoms. The bottom then slopes toward the foredeep as it merges with the broad, shallow depressions lying between the major mountain groups on the northwest. The southern portion of the floor of the gulf blends regularly into the Pacific Ocean.

SUBMARINE MOUNTAINS

GENERAL CONSIDERATIONS

A number of remarkable submarine mountains, termed "seamount" by the United States Board on Geographic Names, rise sharply to heights

of 1 to more than 2 miles above the gulf floor. For convenience, names have been assigned to several of the seamounts. These names have been derived from those of former engineers of the Coast and Geodetic Survey who contributed to the hydrographic development of this region.

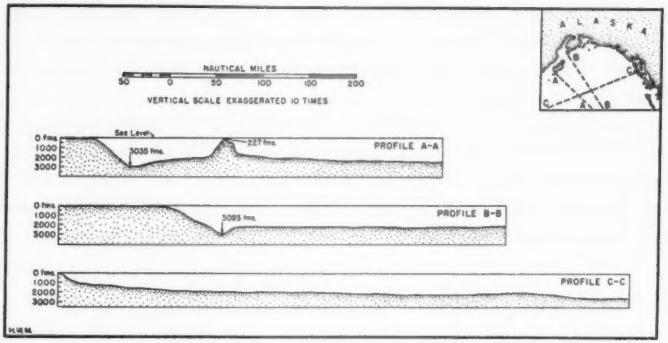


FIGURE 3.—*Profiles of the Gulf of Alaska*

The individual mountains, as contoured, are approximately 10 to 25 miles wide and 15 to 70 miles long at the base. Because they follow a northwestward trend across the gulf, the mountains are somewhat similar in alignment and direction to the Hawaiian and other island arcs to the southwest. Present contouring indicates three or perhaps four major ranges which eventually terminate at the Aleutian Trench to the northwest. The first two ranges trending across the gulf (Pl. 1) begin at Dickins and Hodgkins Seamounts near Queen Charlotte Islands and end with Pratt and Giacomini Seamounts. They rise about 1½ miles above the bottom and reach to within 260 fathoms (1560 feet) of the surface.

A third range shown southeast of Kodiak Island comprises several well-defined groups of mountains including Miller, Faris, and Patton Seamounts. The larger group enclosed by the 2000-fathom contour and centered nearly 200 miles southeast of Kodiak Island rises about 2¼ miles (12,400 feet) above the bottom reaching to within 227 fathoms (1362 feet) of the surface. This is the most remarkable group known (1939) in that it lies so near the Aleutian Trench (Fig. 3), has the greatest height above the ocean floor, reaches the closest to the ocean surface, and is the largest group of mountains discovered in these waters. In height these seamounts surpass the famous mountains of eastern America and even Mt. Etna rising 10,740 feet above sea level or Fuji-

yama with its 12,395-foot elevation. This group, in rising so close to the surface, is over 16,800 feet above the bottom of the Aleutian Trench lying 80 miles northwestward (Fig. 3). The Aleutian Trench as defined by the 2500-fathom curve also decreases in width opposite the second and third ranges of mountains.

A fourth group of mountains which includes Gilbert Seamount lies about 270 miles southeast by east of Kodiak Island. These mountains rise 1¾ miles (9990 feet) above the average bottom and reach within 785 fathoms of the surface.

The steepness of slope and other physiographic details accompanying the aforementioned mountains can be visualized from the natural-scale profiles constructed from significant portions of the sounding lines. Before proceeding further however, the nature of the sounding data should be considered in more detail.

SOUNDING DATA

The horizontal positions of the sounding lines were controlled only by astronomic fixes and dead reckoning. As many as 43 astronomic sights were obtained on one line. When weather conditions permitted, the positions of all important submarine configurations were strengthened by additional sights. Geographic positions so derived under thoroughly satisfactory conditions are usually considered accurate within about 1 minute of latitude or 1 nautical mile. Ideal observing factors, however, were not usually available for each individual sight. Control of sounding lines between astronomic positions was obtained through the usual methods of dead reckoning. Log readings were made at hourly intervals and also whenever the course was changed or astronomic sights were taken. Courses steered were corrected for estimated wind or current velocities and adjusted for closure at the ends of the line.

Recorded soundings were co-ordinated with time between log positions. The average sounding interval was about 5 minutes, equivalent to 1 nautical mile. On some earlier lines, the interval was as much as 15 or 20 minutes. On lines run in recent years, the sounding interval was as short as half a minute (one-tenth mile) in areas of irregular bottom and particularly over some of the submarine features of unusual height or irregular topography.

The soundings were obtained with the Type 312 Fathometer echo sounding machines calibrated for velocities of 800 or 820 fathoms per second. This instrument is essentially a unit which converts directly to visual depth units the time required for a sound impulse to travel down to the floor of the ocean and be reflected back as an echo. For example, when a depth of 2400 fathoms is registered on a Fathometer cali-

brated for a velocity of 800 fathoms per second, the outgoing sound impulse and the returning echo have consumed about 6 seconds of time. The only corrections necessary are briefly those due to (1) the tides; (2) the variation in velocity of sound in sea water due to pressure, temperature, and salinity; and (3) the distance below sea level of the sound impulse oscillator and the hydrophone receiving the echo. In the instance just cited, these corrections may total about 45 fathoms (270 feet) and are added to the Fathometer readings.

From 1925 to 1939 consistent research and improvements of an electrical and mechanical nature have been made in the echo sounding device leading to two practical results—increased accuracy and thoroughness of sounding. On several of the earlier lines, however, a now obsolete sonic device was used, and the soundings so obtained were uncorrected for pressure, temperature, and salinity. This is also true of some of the early Fathometer soundings. The few profiles which were constructed from them can usually be identified by the long sounding intervals indicated on the profiles (Figs. 8-12).

The direction in which a sounding line passes over a physiographic feature frequently causes distortion in the true shape. The natural tendency in analyzing such an echo sounding line profile is to view it as a true vertical cross section. Such a condition is only fulfilled when the line has been run in the most advantageous position or direction, which in turn presupposes that the main characteristics of the feature have already been outlined. In the absence of such previous knowledge, and this is precisely the condition for the profiles here presented, cognizance must be taken of the possibility that many of the echoes have been returned from features which lie outside of a vertical plane passing through the ship's oscillator, the hydrophone, and the ocean bottom. It naturally follows then that portions of the profiles, particularly the side slopes, are actually only apparent vertical sections. Soundings taken at irregular intervals or at intervals closer than 5 minutes of time (about 1 nautical mile) are more frequent after irregular surfaces have already been observed or partially passed over. It is not uncommon, therefore, to note that more irregularity in bottom apparently exists on the declining slope just crossed than on the rising slope encountered as the vessel approaches the feature.

CONSTRUCTION OF PROFILES

The profiles were constructed with equal horizontal and vertical scales. Although this presentation suffers when reduced for publication, such losses are more than offset by the ease with which true relative proportions may be visualized. A natural scale is valuable in studying

the application of slope corrections which are as much as 200 fathoms or 1200 feet.

Figure 4 illustrates the procedure used in constructing the profiles. Recorded positions and soundings were plotted on a datum line (sea

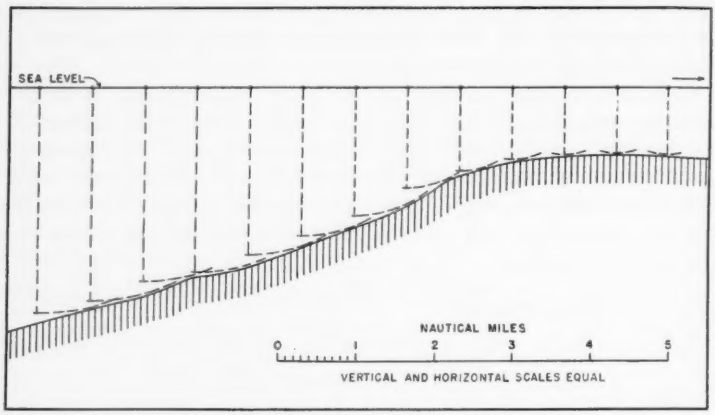


FIGURE 4.—*Method of constructing profiles*

level). The indicated depths were marked vertically below the soundings. Depth arcs were described by using the positions of the soundings on the datum line as centers and the vertical depth distances as radii. A smooth curve was then fitted to the tangent of the arcs, thus completing the profile. In drawing the profile line tangent to the depth arcs it has been assumed that the sounding echo has been reflected along the normal to the bottom. The vertical difference between the plotted depth and the point where the profile line passes directly underneath is equal to a correction for slope. This correction, however, is approximate as it was not derived from the contours (Shalowitz, 1930; Pinke, 1938). In addition, the sounding lines were not always run in such a direction to the submarine feature that all the echoes were returned in the same vertical plane.

The value of the profiles is enhanced by the method of indicating all soundings by small strokes on the datum line (sea level) and at the same time indicating by the direction of the stroke the surface from which the echo was believed to have been reflected and used as a fixed point or arc in constructing the profile. Thus the intensity of soundings is at all times indicated, and it is easy to ascertain to what degree the delineation is

controlled by accepted points or soundings. The reader has further advantage in that when a series of soundings indicates an irregular bottom and the profile is subject to several different constructions, he may determine the actual soundings and verify the interpretation by placing one leg of a divider on the datum line and extending the other along the direction indicated to the point where the profile line is encountered. The arrow on the right of each profile indicates the direction of the vessel.

PROFILE SECTIONS

General statement.—Plate 2 is a reduced copy of a portion of the Coast and Geodetic Survey Chart 9000, edition of April 1934, and is intended to supplement the small scale index shown on each of the profile plates. The geographic positions and lengths of the profile sections are superimposed as straight lines. In all, 49 sounding sections comprising 864 nautical miles of submarine profiles are represented. This procedure of indexing the profile sections shows the general correlation of all sections with respect to each other, to the Gulf of Alaska and the Pacific Ocean, and to the continental margins of Alaska and Canada on a larger scale than would otherwise be practicable. The representative soundings of the entire area show the prevailing depths between and contiguous with the published profiles. It should be noted that practically all sounding sections extend in a general east-west direction. Further details of the bottom adjacent to or between the profile sections may be found in a copy of the United States Coast and Geodetic Survey Chart 9000. (*See also* Bryan, 1940.) This chart, on a scale of 1 to 4,500,000, embraces the entire area and also extends sufficiently southward and westward to include the Hawaiian Islands.

Group I. Pratt, Welker, Hodgkins, and Dickins Seamounts.—Profile A on Figure 5 crosses Pratt Seamount and is an excellent example of a symmetrical section having a width at the base of over 27 nautical miles (standard length of a full profile illustration). Rising from a maximum depth of 2060 fathoms on the east or 2125 fathoms on the west to a minimum depth of 388 fathoms (four successive soundings spaced 0.15 miles apart), it has a maximum height of 1737 fathoms or 10,422 feet above the surrounding ocean floor.

The unusual number of soundings varying from a spacing of three-quarters of a mile to as close as 7 per mile are so distributed as to give a complete profile. The four successive least-depth soundings of 388 fathoms and one of 391 fathoms form only a small fraction of the 63 soundings defining the smooth portion on the summit which is from 6 to 7 nautical miles wide. The smoothness of the summit is further emphasized by the fact that many of the successive soundings occur in

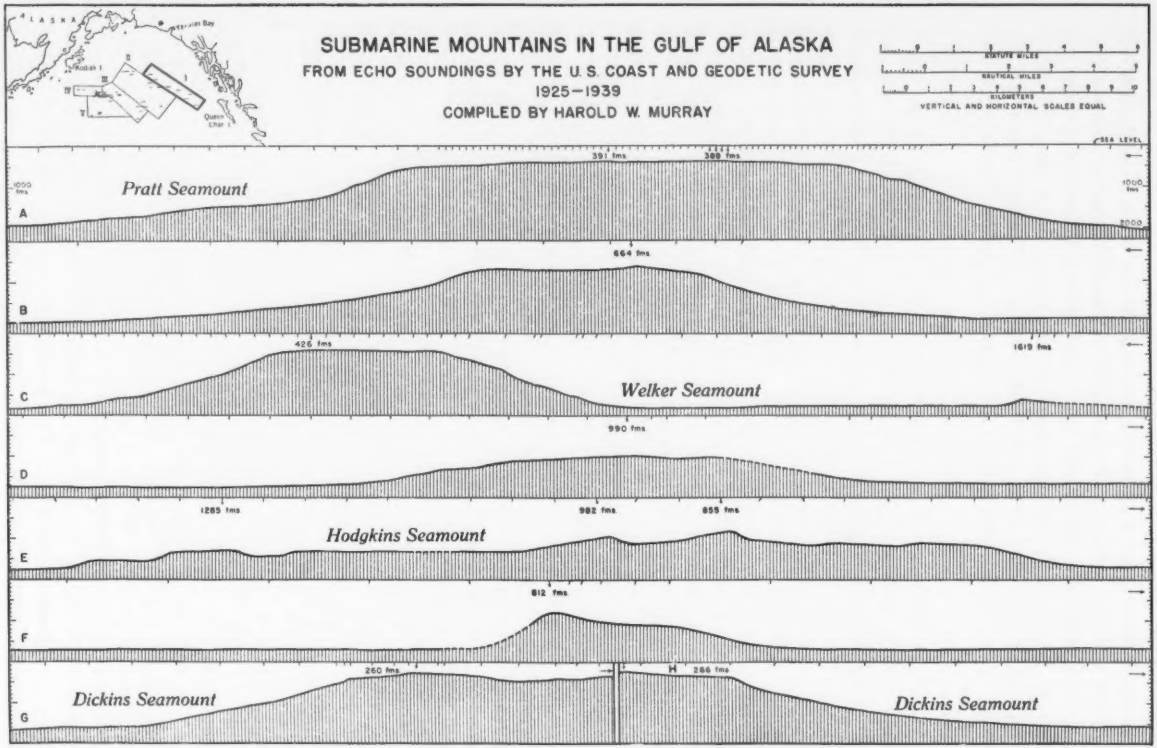
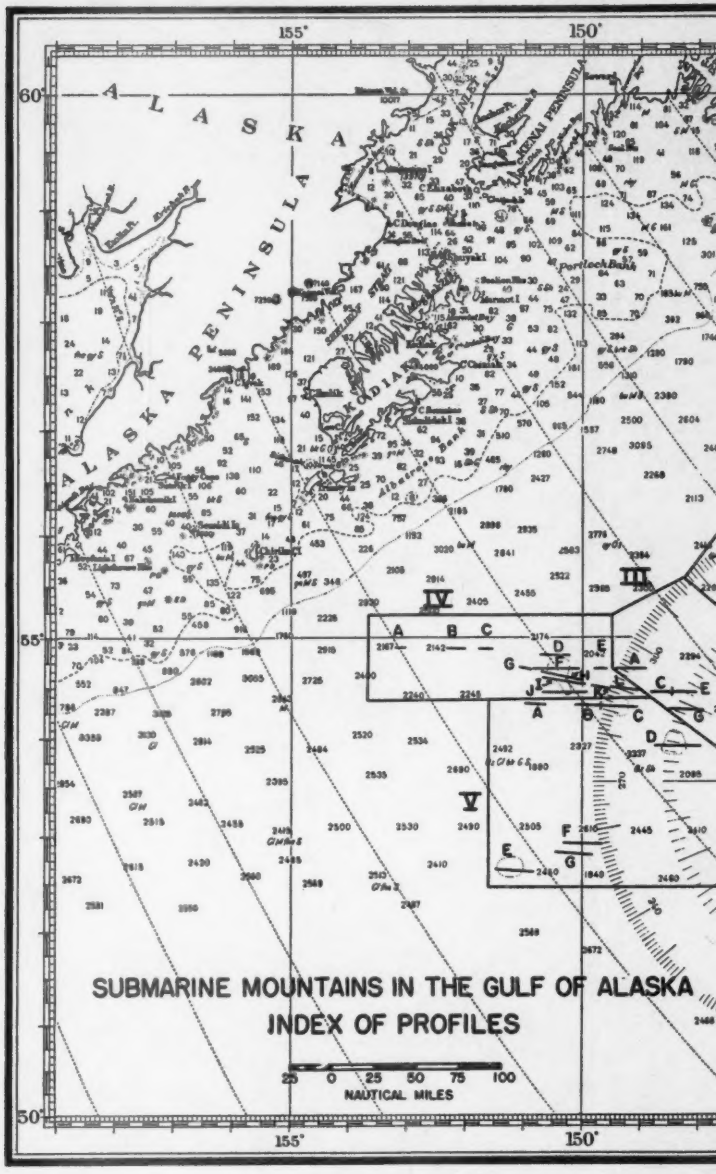
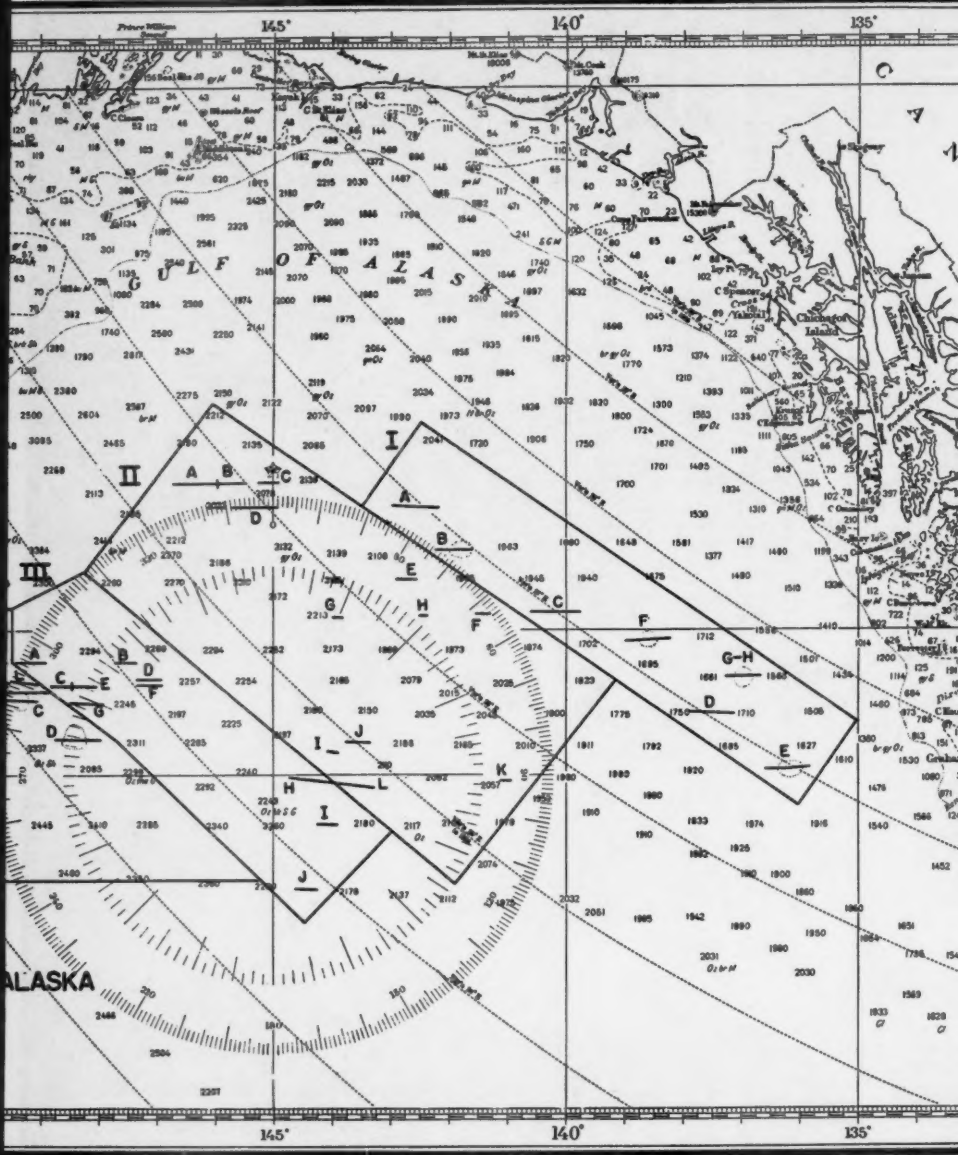


FIGURE 5.—*Group I. Pratt, Welker, Hodgkins, and Dickins Seamounts*



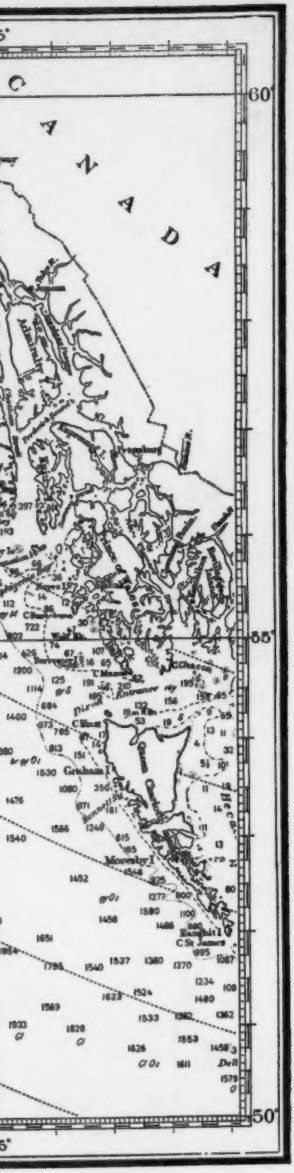
Reduced portion of U. S. Coast
soundings in the Gulf of Alaska

FIGURE 3.—Group I. Pratt, Welker, Hodgkins, and Dickins Seamounts



INDEX OF PROFILES

f U. S. Coast and Geodetic Survey Chart 9000, edition of April 1934, showing representative
Gulf of Alaska and index of five groups of profiles (49 sections totaling 884 nautical miles).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pairs of equal depth. When two successive soundings differ in depth, the difference is never more than 9 fathoms, with a difference of 2 fathoms occurring most frequently.

Well-developed shoulders or steps over 1 to 2 miles in length are barely perceptible in the small scale illustration but are found at an average depth of about 470 fathoms on the eastern edge of the top and at about 480 fathoms on the western edge. They may have some bearing on the geologic history of this feature. The average slope on the east side is 16 degrees, whereas that on the west varies from 22 near the top to 6 degrees on the broader lower portion. A smooth or gently sloping top, accompanied by concave side slopes and occasional shoulders, characterizes many of the profile sections.

Profile B (Fig. 5) is 35 miles southeast of Profile A and 1320 fathoms above the surrounding ocean bottom. The top portion lying at an average depth of about 750 fathoms is about 6 miles wide and has a small crown on the east rising about 85 fathoms or 510 feet above the average level of the top portion. The concavity of the side slopes is clearly illustrated although not developed by many soundings. The sounding sections in Profiles A and B were contoured as one feature. The distance of 25 miles between the two sounding lines, however, is quite large.

Profile C (Fig. 5) crossing Welker Seamount is another flat-topped section about 4 miles wide lying at a depth of 426 fathoms and having a perceptible eastward slope. The variation in depth of the successive soundings spaced about 0.35 mile apart defining the flat portion is 1 to 9 fathoms, with an average of less than 3 fathoms. The limited extent of this feature in a north or south direction is substantiated by the fact that adjacent parallel sounding lines (Fig. 1) passing within 20 miles on both the north and south sides indicate a smooth bottom with variations in successive depths limited to only a few fathoms.

On the eastern portion of this profile a small projection at a depth of 1619 fathoms rises 150 fathoms above the bottom. The broader top portion has an average slope of 8 degrees toward the east and is defined by three soundings spaced about a quarter of a mile apart. The remaining portion of the section just east of the peak, shown by a broken line, is uncertain because no echo returns were heard. The first sounding of 1769 fathoms obtained just west of the highest point could also have been reflected directly from the bottom or from the narrower sloping face. A similar but better developed profile section is shown in Figure 7, Profile H. Fourteen fathoms is the average variation in the successive soundings, spaced 0.9 mile apart, which define the smooth bottom between the small and the large features in this profile.

Profile D (Fig. 5) illustrates a lower feature lying in depths of about 990 fathoms and rising 750 fathoms above the surrounding ocean bottom. An adjacent parallel sounding line passing within 5 miles on the north and another within 20 miles on the south (Fig. 1) show only small hills rising about 117 fathoms above the bottom. The dashed portion on the east side represents the discontinuance of sounding during the interval in which the vessel stopped and again resumed speed in the same direction.

Hodgkins Seamount in Profile E (Fig. 5) lying at a minimum depth of 855 fathoms is quite irregular. Although an increase of soundings spaced at 1-mile intervals would be helpful, there is no reason for questioning the authenticity of those already obtained. The small depressed portion in the western section of the profile is based upon a single 1435-fathom sounding which was obtained between a 1335-fathom depth on the east and a 1285-fathom depth on the west. The actual delineations of the angular portions of this profile are indefinite. In the case of the small depressed portion the profile line has been drawn so as to fit the sounding arc. In reality, however, the echo could have been returned from one of four distinct areas, namely, the west edge, the bottom of the depression, the east edge, or a surface lying outside the plane of the profile. Similar possibilities usually exist in any echo sounding profile in which abrupt steps are shown.

The delineation in Profile F (Fig. 5) found at a depth of 812 fathoms drops to general depths of 1700 fathoms on either side, being more certain on the east than on the west side because of the greater number of soundings spaced at relatively closer intervals. The abrupt western slope of about 38 degrees is over 1½ miles in length and is based on a single 1686-fathom sounding obtained as the vessel approached the rising slope.

Profiles G and H (Fig. 5) are two sections of Dickins Seamount at a depth of 260 fathoms. This feature has a maximum height of 1450 fathoms (8700 feet) above the surrounding ocean floor. The commanding officer, after proceeding eastward as far as shown in Profile G, turned the vessel about, stopped, and attempted to obtain a bottom sample. Although the attempt was unsuccessful, fresh scratches on the sampling apparatus presumably indicate the presence of rock bottom. The sounding line shown in Profile H with a least depth of 266 fathoms was begun about 1 mile due north of the 260-fathom depth in the previous section and a course due east again steered. Some uncertainty will naturally exist as to the exact position of the second line, but because of the good weather conditions prevailing at the time it may be assumed that the eastern section was begun approximately as described.

The mountain represented by the half sections of G and H is 30 miles northeast of that illustrated in Profile D and is nearly twice as high. It is evident, however, that two separate mountains of considerable height exist in close proximity because a third sounding line (Figs. 1, 6) pass-

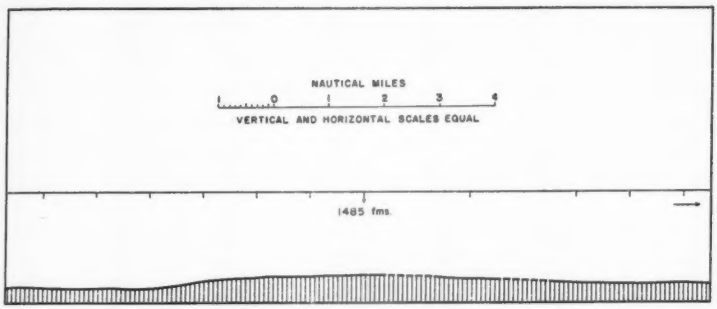

FIGURE 6.—*Section of sounding line*
Run between Profile D and Profiles G and H (Fig. 5).

ing between the two mountains shows a variation in the ocean bottom of not over 265 fathoms. This swell found at a minimum depth of 1485 fathoms extends over a distance of 8 miles and is therefore quite gentle. The small extent of the higher mountain (Profiles G, H) in a northerly direction is confirmed by another sounding line passing within 7 miles on the north (Fig. 1) which shows a fairly uniform bottom. On the contour map (Pl. I), this mountain has an oval shape and a maximum dimension of 20 miles at the base.

Group II. Giacomini Seamount.—On Figure 7, Profiles A, B, and C are all on the same sounding line and are continuous except for a gap of 7 nautical miles between Profiles B and C where the Fathometer was out of order and no soundings were obtained. With the exception of this gap, 54 miles of continuous profiles are represented. The highest of these profile features, Giacomini Seamount, is 1869 fathoms or 11,214 feet above the surrounding ocean bottom. The lesser profile features have heights of 390 and 470 fathoms above the general ocean bottom.

Giacomini Seamount in Profile A (Fig. 7) slopes upward to a single peak at a depth of 431 fathoms and represents another distinct section recurring in these profiles. The "dead spot" directly over the peak where no echoes were heard for 4 minutes would indicate that the topography is so rugged as to deflect the echoes away from the ship's hydrophone. Least depths, shoaler than the recorded value of 431 fathoms, are there-

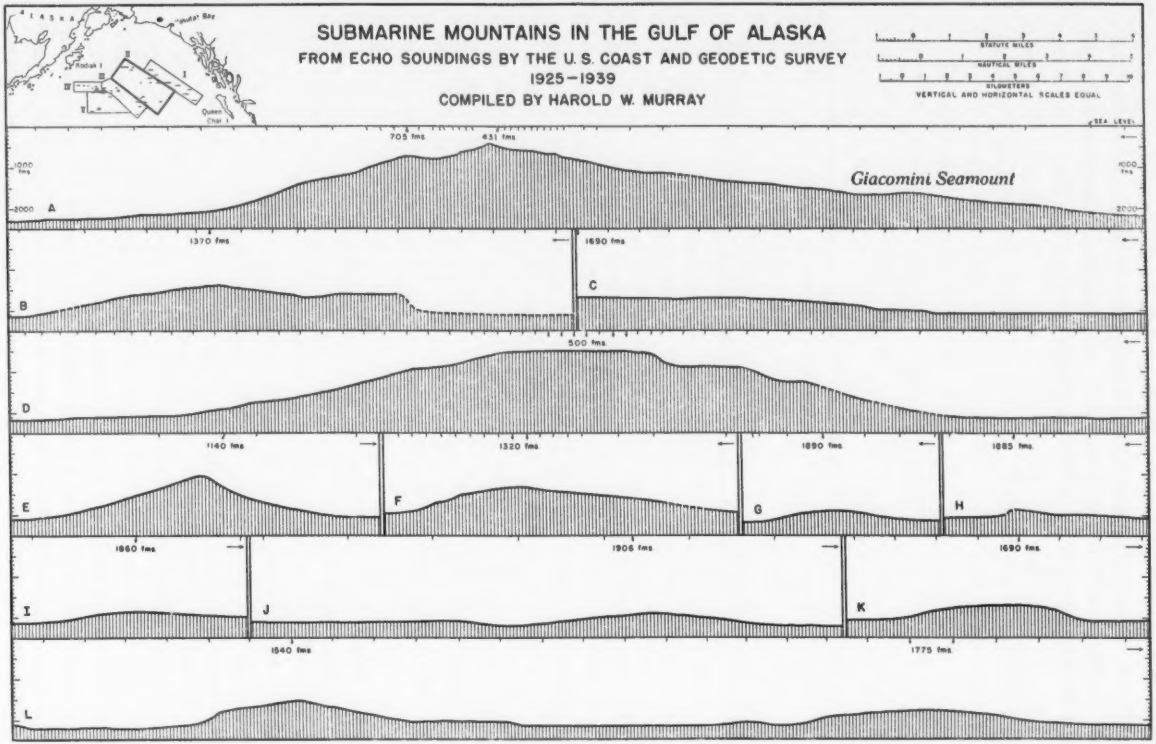

FIGURE 7.—*Group II. Giacomini Seamount*

fore highly probable in this vicinity. At a depth of 655 fathoms a small shoulder about 1½ miles east of the peak was constructed from a single sounding and could possibly have been reflected from a feature outside the plane of the profile. Another shoulder, based upon three sounding arcs intersecting at a common point, lies at a depth of 630 fathoms about three-fourths of a mile west of the peak. Two miles west of the peak a small crown is shown at a depth of 705 fathoms. The deepest sounding recorded just east of this crown was 780 fathoms. The side slopes of this profile are undulating and yet contrasting with respect to the rate of slope. The rapid drop on the west side occurs within a distance of 7 miles, whereas the descent on the east takes place in twice the horizontal distance. Near the lower portion of the east side two distinct slopes of 7 degrees with lengths of about 5 miles are shown.

The small plateau at a depth of 1595 fathoms near the eastern portion of Profile B drops quickly to a depth of 2010 fathoms where there is a difference in elevation of 415 fathoms or over a third of a mile. It is possible that this lower portion is questionable because the five soundings varying from 2010 to 2100 fathoms were taken immediately after the Fathometer was in working order. There appears to be no reason, however, to question the four soundings of about 1595 fathoms taken at 5-minute intervals defining the top of the plateau.

Profile D (Fig. 7) is another example of a well-defined flat-topped section 3 miles wide with shouldered and concave sides. This feature rises from a general depth of 2165 fathoms and has a height of 1665 fathoms (9990 feet). It was found on a sounding line about 5 miles south of and parallel to Profile C. Five of the soundings defining the flat top (spaced 0.3 mile apart) were obtained at equal depths of 500 fathoms. At depths of about 910 fathoms shoulders occur on either side; the shoulder on the west side, however, is less pronounced and barely half the width of the shoulder on the east which is 1½ miles wide and defined by four soundings varying from 895 to 925 fathoms. The limited extent of the features shown in Profiles A, B, C, and D in a north-south direction is indicated by the fact that one east-west parallel line (Fig. 1) run about 10 miles to the north and another about 30 miles to the south indicate a remarkably smooth bottom.

Profile E (Fig. 7) shows a feature rising rapidly to a height of about 1 mile above the surrounding ocean bottom. This delineation, it should be noted, is based on only three soundings spaced 0.8 mile and 1.6 miles apart.

The small feature in Profile H (Fig. 7) found at a depth of 1885 fathoms has a height of about 150 fathoms and slopes eastward at a

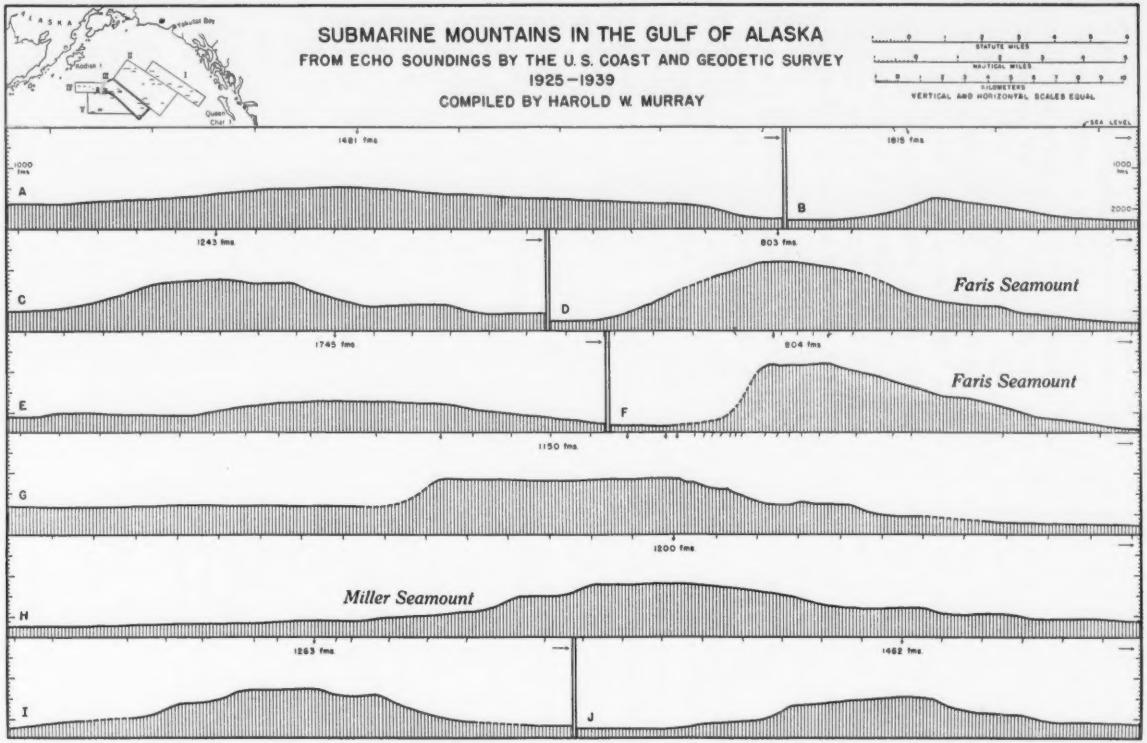

FIGURE 8.—*Group III. Faris and Miller Seamounts*

rate of about 7 degrees. This feature is very similar to that shown in the eastern portion of Profile C, Figure 8 in that the heights are identical, and the slopes agree within 1 degree and trend in the same easterly direction. Both of these features were discovered on the same sounding line but are about 85 miles apart.

Profiles F, G, and I to L on Figure 7 illustrate a number of sections of lesser magnitude having heights of a quarter to a half-mile above the ocean floor. Whether several of these are simply slices of larger features cut at lower levels or will ultimately possess much the same magnitude and form as depicted will only be known when sufficiently complete surveys are made.

Group III. Faris and Miller Seamounts.—The profiles on Figure 8 are localized in two areas on the plate outline: one on the northwest including Faris Seamount and the other on the southeast including Miller Seamount. The southeastern area (Profiles H, I, and J) is related to Profiles I, J, and L on Figure 7. From the fact that seven sounding lines run in the latter vicinity have not revealed any features having depths shoaler than 1200 fathoms or rising more than one fourth to three fourths of a mile above the ocean floor, one may infer that few if any other mountains of much greater height exist in this locality. The present sounding line spacing of from 10 to 30 miles, however, is far from being conclusive.

The smaller features in Profiles A, C, E, and G rising from half a mile to over 1½ miles above the general ocean bottom in the northwest portion of Figure 8 may, in a broad sense, be spoken of as the foothills of the more imposing mountains described in Figures 10 and 12.

The top portions of Faris Seamount shown in Profiles D and F (Fig. 8) were both found at a depth of about 804 fathoms. This seamount is of considerable magnitude since it rises 1600 fathoms or 9600 feet above the surrounding ocean floor. The profiles are from two parallel sounding lines spaced approximately 2 miles apart and are doubtless sections of the same feature. The northern section has a rounded top which may be due in part to the widely spaced soundings. Another significant aspect, or perhaps simply a coincidence, is that no echo returns were heard at the third sounding interval on either the east or west slope where echo returns of approximately 1225 and 1550 fathoms respectively would ordinarily have been expected. The top portion of the lower section (Profile F) has small peaks or crowns found at depths of 804 fathoms on either side. The three soundings obtained between these two crowns are 16, 51, 51 fathoms deeper respectively, with the two latter depths existing on the west side. Both profile sections have shoulders on the

east slope. A difference of 200 fathoms or 1200 feet, however, exists in the shoulder levels.

The delineation of the west slope of Profile F (Fig. 8) is quite abrupt and is reproduced with soundings in Figure 9. Reading toward the left,

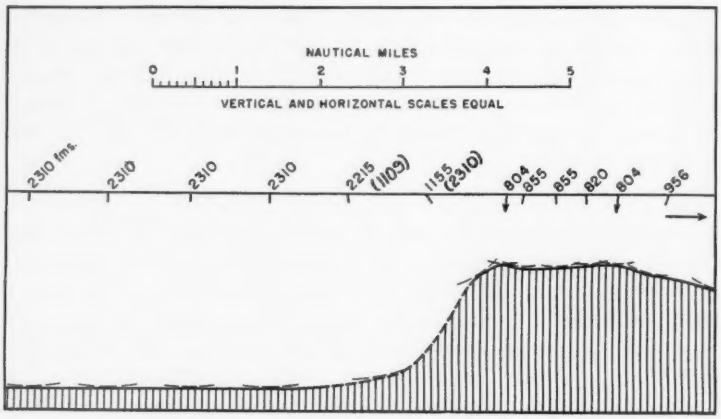

FIGURE 9.—*Section of Profile F (Fig. 8)*
Showing soundings used in constructing the profile.

the first sounding of 2310 fathoms 1 mile west from the second 804-fathom sounding was rated as a "poor" echo. Between this sounding and the next sounding of 2215 fathoms 1 mile farther west, an echo at 1109 fathoms rated as "good" was recorded but not timed exactly. It may therefore have occurred anywhere between the other two soundings but more probably nearer the first sounding of 2310 fathoms. The fact that the 1109-fathom return was stronger suggests that the weaker 2310-fathom return may have been a double echo since half this return is equal to 1155 fathoms, a not uncommon occurrence. The latter value was therefore used as the first sounding down the west slope. The next sounding of 2215 may also be in error as the peak (804 fathoms) to the east would still be within less distance by 200 fathoms than 2215 fathoms. It is not impossible, however, that an echo of 2215 fathoms was received from the bottom nearly under the vessel. If such a steep slope was actually encountered, confused echoes were obtained. It is also possible that these soundings are erroneous because of limitations of the instrument (Smith, 1939), and this profile should accordingly be used with due regard to the considerations mentioned. It is important to note that

four cases of this nature (Profile F, Fig. 5; Profiles F and G, Fig. 8; Profile J, Fig. 10) have two points in common, namely, that they exist on the approach side (a technical aspect) which is also the west side (a physiographical aspect) of the feature in question.

The larger portion of the foregoing mountain feature in Profiles D and F (Fig. 8) appears to be confined within a limited area. One sounding line run 12 miles to the south (Fig. 1) has continuous depths of about 2250 fathoms. Another line passing 10 miles to the north shows similar depths except that an 1815-fathom indication (Profile B) was obtained about 15 miles to the northwest. This mountain as contoured includes Profiles B, D, and F and has a northwest-southeast trend of 30 miles and a width of about 10 miles at the base.

The feature in Profile G (Fig. 8) lies in depths of 1150 fathoms. The smooth, slightly concave top has a width of 6 miles and is defined by 8 soundings spaced about 0.9 mile apart. Four of these soundings have like depths of 1150 fathoms. The deepest sounding of 1205 fathoms obtained in the middle of the top portion is only 55 fathoms deeper than the 1150-fathom depths near the edge. The side slopes of this feature are contrasting. The western slope encountered as the vessel approached the feature is abrupt and decidedly uncertain. This portion of the profile was constructed along the arc of a single 1855-fathom sounding. Another significant point is that no echoes were received at the regular 5-minute sounding interval 0.8 mile to either side of this sounding. The eastern slope is defined by soundings spaced as close as 0.15 mile. Several of the echoes, however, were apparently returned from common points and thereby increase the difficulty of fitting in a reasonable profile line.

Profile H (Fig. 8) crosses Miller Seamount and in rising from depths of 2240 fathoms to depths of 1200 fathoms has a height of 1040 fathoms. The profile is continued on Figure 7 as Profile L, and taken together they illustrate 54 nautical miles of continuous bottom. Shoulders 1 to 2 miles wide exist on either side of this mountain; the large shoulder on the west side rises 345 fathoms above the lesser lower shoulder and is 280 fathoms below the top portion of the profile.

The feature in Profile I (Fig. 8) is quite symmetrical and lies at a depth of 1263 fathoms. The top portion defined by only three soundings is about 2 miles wide and is apparently quite level since the other two soundings spaced 0.6 mile apart obtained on the west side are both at depths of 1289 fathoms. The 1263-fathom depth was noted in the records as the shoalest sounding observed in this section. The shoulders on the sides are about 1 mile wide, that on the west side being 282 fathoms below the top portion, whereas that on the east side is 195 fathoms below

the top. One notable characteristic of this entire profile is that about two thirds of the echo returns were of such low intensity as to warrant a rating of "weak" or "faint." The dashed portions of this profile represent areas in which no echo returns were heard. An adjacent parallel sounding line passing about 10 miles to the south (Fig. 1) shows a smooth bottom with a maximum variation in successive soundings limited to about 25 fathoms.

The low feature in Profile J (Fig. 8) defined by soundings spaced at 1-mile intervals rises about 778 fathoms above the surrounding ocean bottom. The top portion is smooth and slopes westward at a rate of about 5 degrees. The shoulders, 1 to 1½ miles wide, occur at about the same distance below the top portion, that on the west being at 394 fathoms and the other on the east at 372 fathoms. An interesting aspect of this formation is that another sounding line (Fig. 1) passing about 2 miles northward in the same direction shows a lower section rising 345 fathoms above the surrounding ocean bottom. The latter profile shows a flat top about 2½ miles wide in depths varying from 1830 to 1855 fathoms with the shoaler portion being near the middle of the section. The base of this section is about 7 miles wide but on the western approach side no echo returns were heard at two successive sounding intervals spaced 0.9 mile apart.

Group IV. Patton Seamount.—Figure 10 illustrates the highest and best-developed group of submarine mountains discovered in these waters (1939). They are the most spectacular features of the entire series and are only about 200 miles off Kodiak Island. Developed by six sounding lines spaced 3 to 9 miles apart, this remarkable mountain range has been found to reach within 227 fathoms of the surface of the ocean and in rising from general depths of 2300 fathoms it attains a magnificent height of 2073 fathoms or 12,438 feet above the ocean floor. This height closely approximates the elevation above the sea level of Mauna Loa in the Hawaiian Islands.

Profiles F, H, I, and J (Fig. 10) are by virtue of their proximity probably all part of the higher portions of Patton Seamount. The summits or relatively flat portions are in general found to the east and are also accompanied by steeper sides on the east than on the west. Profile I is particularly well developed and has a width of about 20 miles at the base. Nineteen soundings, 11 of which were at 426 fathoms, were obtained on the summit which has a width of 3½ miles. The greatest depths obtained on this flat plateau, two successive 431-fathom soundings, were found just east of the middle of the section. A depth of 416 fathoms

exists between the two 401-fathom soundings on the crown on the west. On the east side, two adjacent soundings of 426 fathoms do not disclose any crown. Such a formation, however, is found about 1 mile westward at a depth of 406 fathoms, and indicates a small 20-fathom rise in the bottom. Although the maximum difference between depths obtained on the summit is only 30 fathoms, greater differences can exist because of the nondirectional nature and inability of echo soundings to register at all times the sharp or narrow depressions in the bottom (Smith, 1939). The well-developed shoulders having widths of 2 to 2½ miles on the west slope occur at average depths of about 577, 906, and 1440 fathoms.

Profile F (Fig. 10) which is 6 miles farther north follows the construction just discussed but is not controlled by so many soundings. Of particular interest is the summit which is 3½ miles wide but slopes more perceptibly to the east at a rate of about 2 degrees to a depth of 474 fathoms. The least depth of 396 fathoms is only 5 fathoms higher than the adjacent sounding just westward and only 5 fathoms less than the least depth, 401 fathoms, noted on the previous Profile I. The concavity of the slope on the east is well illustrated but is based on only six soundings. The side slopes of both Profiles F and I are considerably greater on the east than on the west side.

Profile H is between Profiles F and I (Fig. 10). The top portion found at a depth of 227 fathoms is 169 fathoms higher than that of Profiles F and I. The rounded side slopes are partially due to the paucity of sounding data in that the 11 soundings are spaced 1 to 3 miles apart. These soundings were obtained with a 1925 sonic device long since obsolete but are nevertheless of sufficient accuracy to warrant retention. Historically significant, this line was the first sounding line of the series run across the Gulf of Alaska. In the 15-year period that has elapsed since the year 1925 no other submarine feature rising so close to the surface (227 fathoms) or so high above the general ocean floor (2073 fathoms) has yet been found in these waters.

Profile J (Fig. 10) is about 10 miles south of Profile I. Its round shape suggests that it is on the side of a larger feature, probably Profile I to the north. A full length 27-mile section demonstrates the smoothness of the ocean floor within the limits of the section for about 9 miles on either side. Another interesting point is that the ocean floor on the east side of this section as well as of the others just mentioned is from 250 to 700 fathoms higher than on the west. The east slope of the profile is smooth; the west slope is quite abrupt and should be tentatively accepted. The problems encountered are similar to those discussed in detail in Profile F, Figure 8. The 1476-fathom sounding (Fig. 11) could

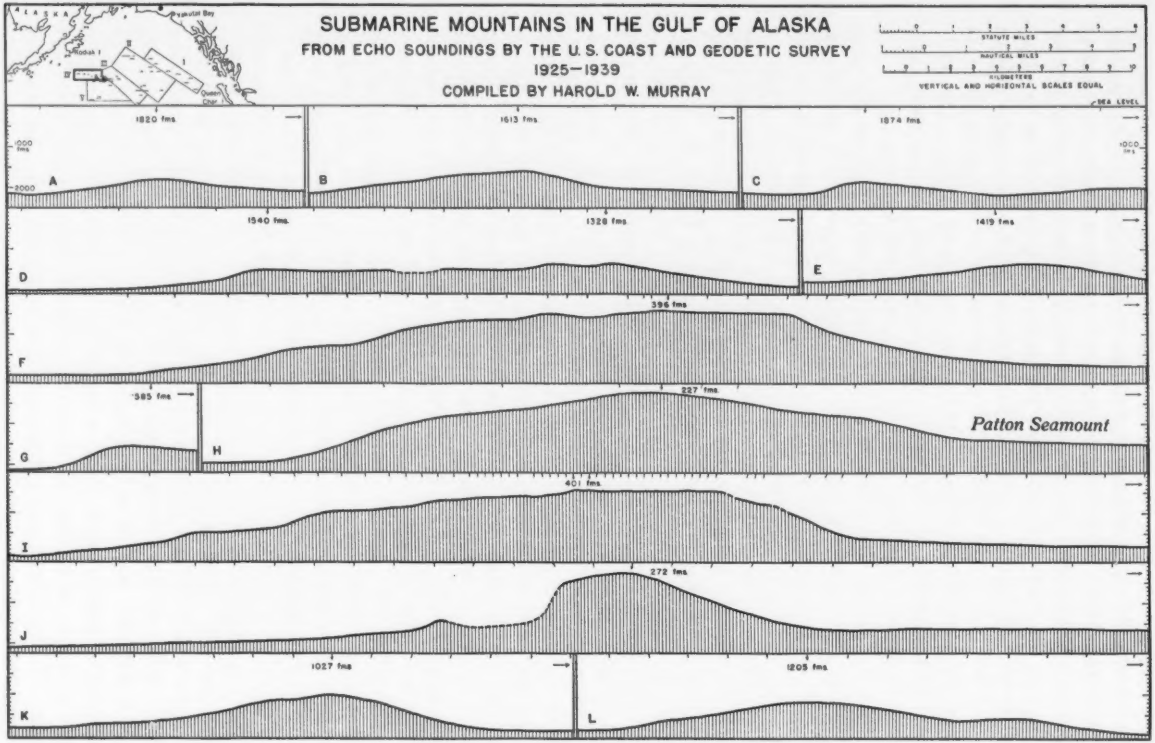

FIGURE 10.—*Group IV. Patton Seamount*

have been received from nearly under the vessel. If the sounding was actually received from the higher portion of the slope, it is possibly in error because the higher section of the profile is 300 fathoms nearer the 1476-fathom sounding arc. The next sounding of 1580 fathoms

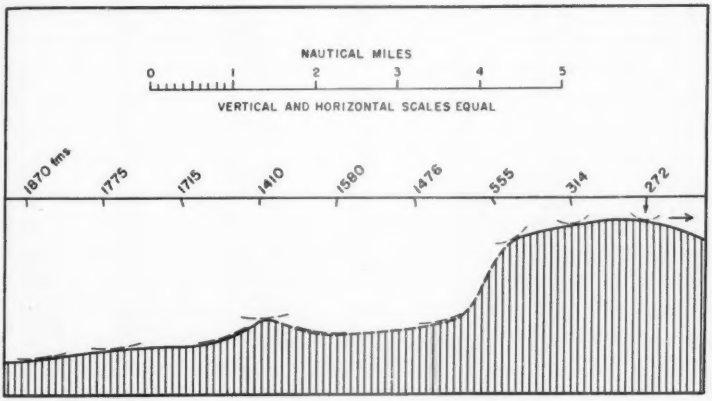

FIGURE 11.—*Section of Profile J (Fig. 10)*
Showing soundings used in constructing the profile.

could have been received from the bottom, from higher up the slope on the west side, or perhaps on the east slope provided the correct delineation is other than that here shown. Other considerations include the possibility that they were double echoes or were reflected from features lying 300 to 600 fathoms outside the plane of the profile.

Little comment on the remaining eight profiles (Fig. 10) which rise as high as 868 fathoms or 5208 feet above the surrounding ocean floor is necessary. Profiles A, B, C, and E are each characterized by paucity of data, for the soundings are spaced at average intervals of about 2.5 miles. The first three profiles are of interest in that they are within 10 to 25 miles of the southern rim of the Aleutian Trench. Profile D, about 10 miles north of Profile F, has an unusual westerly portion in that it levels off for a distance of 6 miles at a depth of about 1540 fathoms. The small dashed portion about 1 mile wide and 100 fathoms below the level surface is based on a single sounding and should not, of course, be considered as entirely conclusive. Two miles farther east this profile rises in steps of 130 and 88 fathoms respectively and then slopes downward at about 9 degrees.

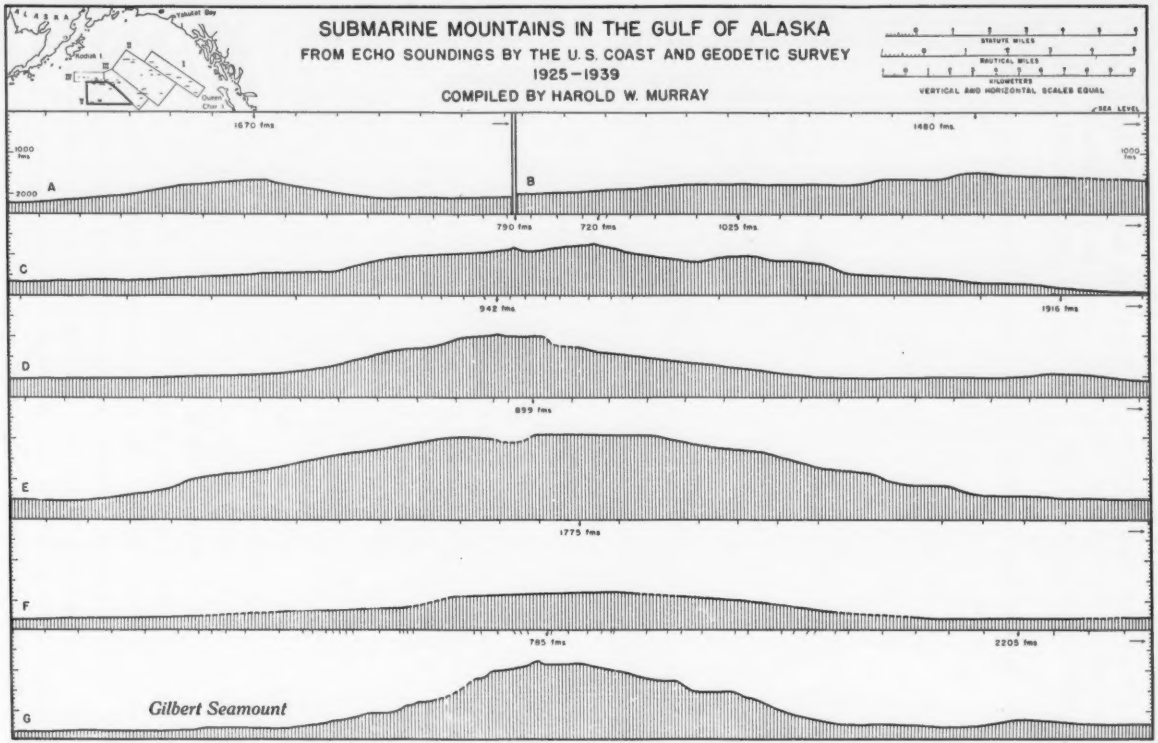

FIGURE 12.—*Group V. Gilbert Seamount*

The feature in Profile G (Fig. 10) is controlled by only two soundings. The difference in depth is 525 fathoms or 3150 feet. A gap of 5½ miles in which only two soundings were taken exists between Profiles G and H. These additional soundings, if representative, would indicate that the intervening area has a slope of about 9 degrees to the east until it joins Profile H.

The rise in Profile K (Fig. 10) has a height of 868 fathoms or 5208 feet above the surrounding ocean bottom. A gap of 2½ miles with smooth bottom at depths of about 1800 fathoms exists between this profile and Profile I. The intervening section illustrates that these mountainous features rise directly from the sea floor without extensive side slopes.

Group V. Gilbert Seamount.—The first four profiles on Figure 12 are additional sections related to the group of mountains in Figure 10. The smaller features shown in Profiles A, B, and C were obtained on the same sounding line (Fig. 1) which was run about 10 miles south of Profile J on Figure 10. A gap of 18 miles with depths of 1975 to 2145 fathoms exists between Profiles A and B. Profile B joins Profile C on the west, and the two combined show 42 miles of continuous profiles. Profile B has two pronounced steps near the middle portion rising first 140 fathoms and then 175 fathoms where a difference of 500 fathoms exists above the western limit. The top portion slopes 3 degrees east for a distance of 5 miles at which point an ascent up a 2-degree slope begins on Profile C.

The highest point, at a depth of 720 fathoms on Profile C (Fig. 12), is 1260 fathoms above the western limit of Profile B. The two peaks on this profile have a difference in depth of 70 fathoms. The intervening portion is 110 fathoms below the secondary peak and slopes up toward the higher peak at a rate of 8 degrees. A general characteristic of this profile is the tendency of the soundings to line up in straight-line groups. Both the eastern limit of Profile C and the western limit of Profile B are similar in depth, being 1950 and 1985 fathoms respectively.

Profile D (Fig. 12) rising 1094 fathoms above the surrounding ocean floor is the southeasternmost feature described in this region. The small peak is about 75 fathoms above the edge of the shoulders. The shoulder on the east slope has an abrupt step of about 200 fathoms. Since the sounding of 1212 fathoms used in defining the western portion of the step was obtained after the watch on the surveying vessel was changed, it is possible the new observer read the sounding 200 fathoms too deep, but as this seems unlikely the sounding has been utilized. Another consideration, provided the observation is correct, is that the echo was reflected

from a feature lying outside the vertical plane of the profile. The small hump found at 1916 fathoms near the eastern limit of this profile is defined by a single sounding and rises about 124 fathoms above the bottom.

The feature in Profile E (Fig. 12) attains a height of 1630 fathoms (9780 feet) above the surrounding ocean floor. The flat summit, 3 miles long and sloping 1 degree downward toward the east, is defined by four soundings spaced 0.9 mile apart which plot as a straight line. The portion of the profile directly west is based on a single 1072-fathom sounding and is about 150 fathoms deeper than the mean of the two adjacent depths. This sounding may not be accurate, but two items tending to verify its correctness are (1) the sounding directly west (988 fathoms) indicates a downward slope and (2) the 1072-fathom sounding was obtained on an odd-time interval indicating that the unusual nature of the bottom as reflected on the Fathometer dial was apparent to the observer, who moreover, deemed it of sufficient prominence to record. It is also possible that these soundings were reflected from a feature lying outside the profile. The shoulders near the base of the east slope are weakly defined.

Profiles F and G (Fig. 12) are two sections crossing Gilbert Seamount and were constructed from two sounding lines spaced about 10 miles apart. An interesting aspect of Profile F is the smooth top occurring at a height of 660 fathoms above the ocean bottom. This top portion is composed of two sections 3 to 4 miles long with the one sloping downward 3 degrees west and the other 4 degrees east. The step on the west side (broken line) rises 310 fathoms. No echo was received by the ship at the regular sounding interval when passing over this portion of the profile. The other broken line portions of this profile likewise represent sections in which no echoes were received.

The top portion of Profile G (Fig. 12) lying in depths of 785 fathoms rises 1715 fathoms or 10,290 feet above the surrounding ocean bottom. Many of the soundings were apparently reflected from common points or possibly features lying outside the plane of the profile thereby leaving the intervening portions of the profile a matter of interpretation. This is further complicated by the fact that attempts to obtain a number of additional soundings at 1-minute intervals (0.2 mile) over the mountain peak were unsuccessful because of no returning echoes. A least depth, shoaler than 785 fathoms, is therefore probable in this section. The side slopes of the mountain are composed of several steps having heights of about 100 to 300 fathoms and are usually constructed from

a single sounding. On either side of the base of this mountain small swells of about 35 fathoms on the east side and 65 fathoms on the west side are perceptible.

CONCLUSIONS

The submarine mountains here described testify to the strong relief existing in the Gulf of Alaska. If the regions embracing the mountainous areas show promise of yielding important scientific information or have some economic significance, it is quite within the limitations of present surveying methods as developed by the United States Coast and Geodetic Survey to make special investigations. Survey vessels, meanwhile, will continue to run sounding lines so as to reduce by half the present sounding line spacing of 25 to 30 miles. Cross sounding lines will also be run which will provide a basis for such adjustments as may be necessary. Future hydrography will probably accomplish the following results:

(1) Disclose more irregularities in the present contours yet preserve the general trend.
(2) Add more details to present information on the seamounts shown in the contour map.
(3) Discover the existence of other mountains related to or dissociated from those already indicated resulting in a more precise delineation of the present apparent ranges.
(4) Reveal more significant factors relating to the actual shape and origin of the continental shelf, foredeep, submarine mountains, and floor of the gulf.

The knowledge here disclosed by a series of sounding lines begun just 15 years ago will be augmented by future development and use of newer sounding devices.

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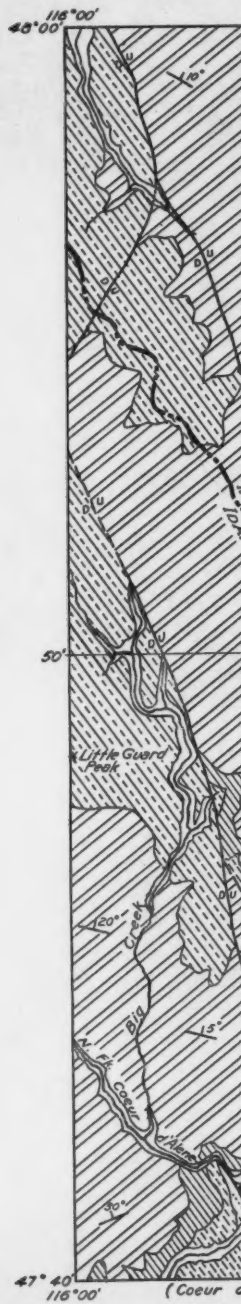
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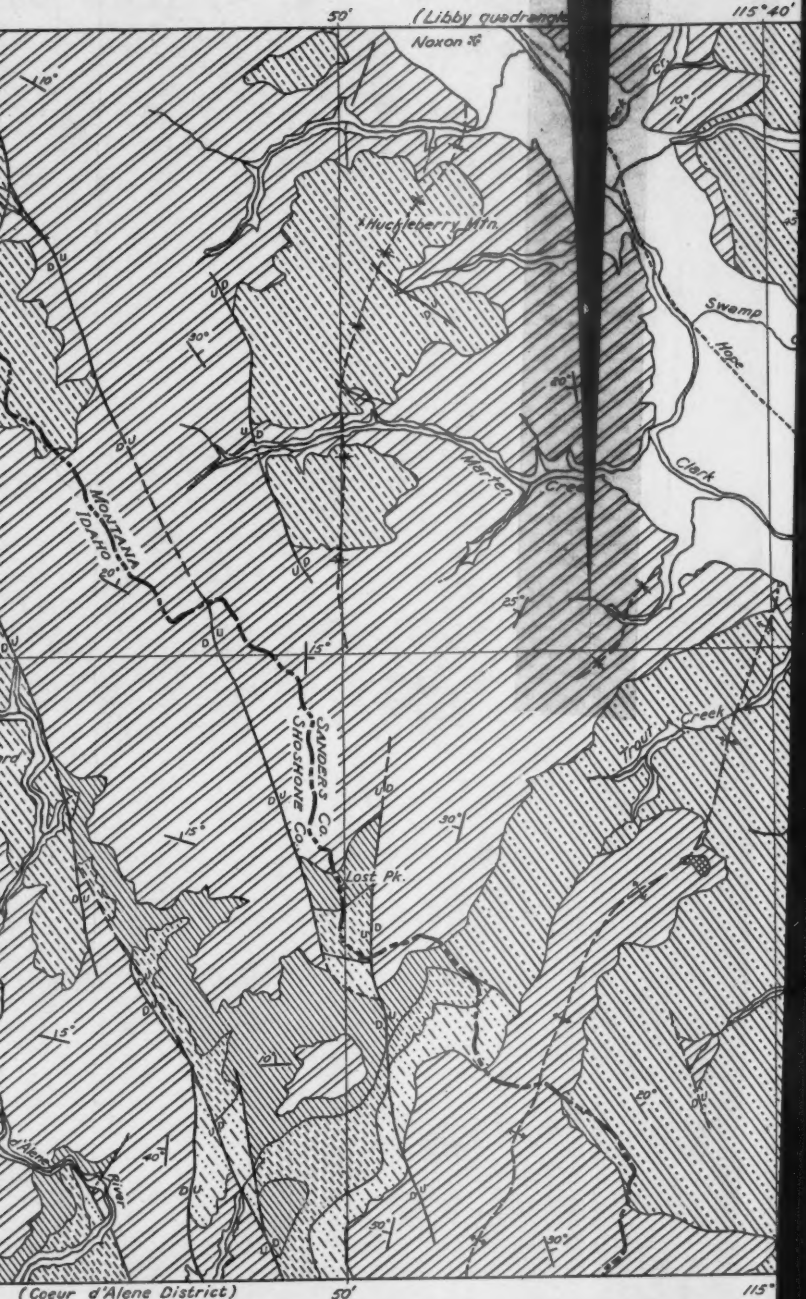
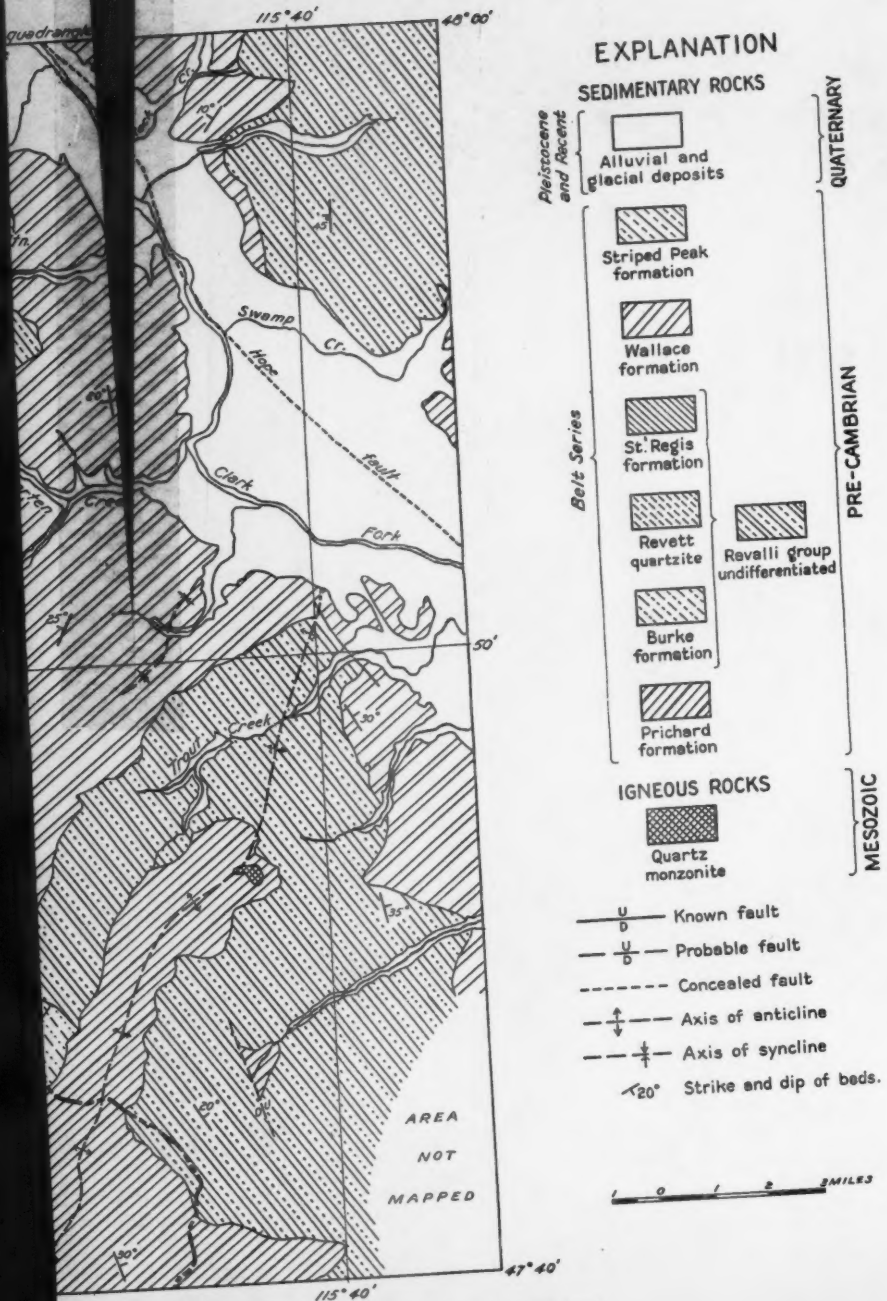


GEOLOGIC MAP OF PART OF THE TROUT CREEK QUADRA

Area lies between the Coeur d'Alene district and the Libby quadrangle. (



HE TROUT CREEK QUADRANGLE, MONTANA-IDAHO

e district and the Libby quadrangle. (Mapped by W. F. Jenks.)

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STRATIGRAPHY OF THE BELT SERIES IN LIBBY AND TROUT CREEK QUADRANGLES, NORTHWESTERN MONTANA AND NORTHERN IDAHO

BY RUSSELL GIBSON, W. F. JENKS, AND IAN CAMPBELL

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ABSTRACT

Three formations of the Belt series—Prichard, Wallace, and Striped Peak—can be traced northward from the northeastern part of the Coeur d'Alene district, Idaho, through the Trout Creek quadrangle to the northern part of the Libby quadrangle, Montana.

The differences upon which the separation of the Burke, Revett, and St. Regis is based in the Coeur d'Alene district, however, become less definite northward and fail entirely beyond the Clark Fork. In the area under consideration, therefore, these three are grouped under the term Ravalli according to the usage adopted by Calkins.

Stratigraphic details of parts of the Ravalli group and the Wallace and Striped Peak formations are given in tabular sections. Certain beds of the Wallace in the Trout Creek quadrangle show "molar tooth" structures similar to those of the Siyeh and Kitchener formations along the international boundary. In the Libby quadrangle both the Wallace and the Striped Peak contain beds of dolomitic limestone showing fossil algal forms similar to those in Glacier National Park.

INTRODUCTION

The Belt series, which comprises the largest known area of late pre-Cambrian sedimentary rocks in North America, is exposed in western Montana, northern Idaho, southern Alberta, and British Columbia.

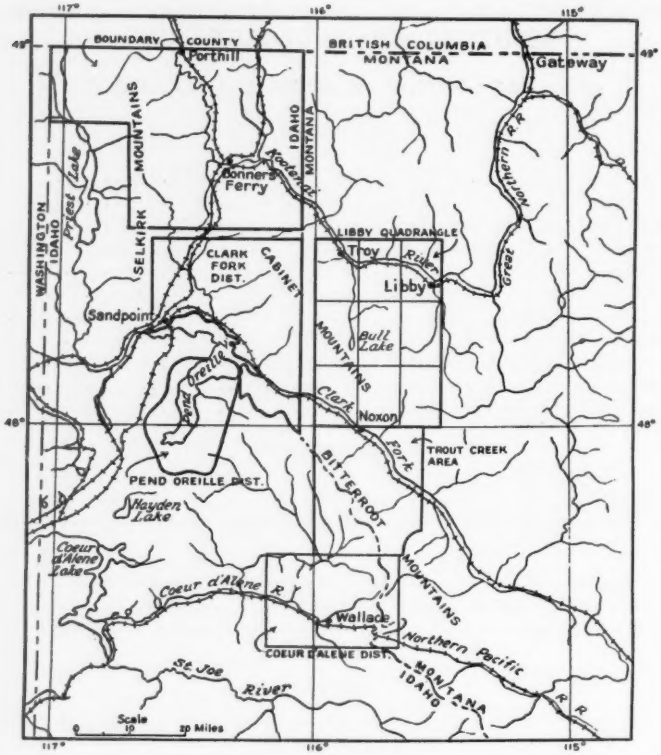

FIGURE 1.—*Index map*

Showing location of Libby and Trout Creek areas and adjacent districts in Montana and Idaho.

Since Peale (1893) first named the series in the Three Forks region of Montana, many problems of the terrane have been formulated. Every student of Belt rocks has encountered difficulty in recognizing and correlating the formations because of resemblance of one formation to another, lateral variation within formations, absence of reliable fossils, and isolation of the districts in which the work was done.

This paper summarizes new data on the Belt series obtained during the mapping of the Libby quadrangle, Montana, and part of the Trout Creek quadrangle, Montana-Idaho, in the summers of 1929 to 1935 (Fig. 1).

TABLE 1.—*Generalized tabular section of Belt Series*

In Libby quadrangle and central part of Trout Creek quadrangle.

(Measurements in feet)

Formation		Libby quadrangle	Trout Creek quadrangle
Striped Peak formation	Upper member	Gray to greenish-gray shale and argillite; thin-bedded gray sandstone; and slightly ferruginous, magnesian limestone. 6000+	Gray, greenish, and red shale, sandy shale, and quartzite; algal dolomitic limestone. 3700+
	Lower member	Dark-red to purplish ferruginous sandstone and quartzite; red sandy shale; minor amount of algal dolomitic limestone. 2000+	
Wallace formation		Gray to greenish-gray sandy argillite; gray, greenish-gray, and brownish sandstone; gray to buff, thinly bedded soft shale; deep red, ferruginous sandstone and sandy shale; gray to white dolomitic limestone, in part algal. Shale, argillite, and sandstone are in part calcareous or dolomitic. 16,500	Gray and gray-green argillite, shale, shaly sandstone, quartzite, and dark-gray dolomitic limestone. 10,500
Ravalli group	St. Regis formation	Upper part: thin-bedded sandy, slightly calcareous shale and argillite.	Red, green, and gray sandy shale. Some quartzite near base. 1000–1700
	Revett quartzite	Middle part: even-grained, gray to white quartzite and quartzitic sandstone.	Massive white quartzite and gray argillaceous sandstone and quartzite. 1200+
	Burke formation	Lower part: dark-gray, sandy shale. 7000–10,000	Gray sandstone, sandy argillite, and quartzite. Grades into Revett type of quartzite above and into Prichard type of shale and argillite below. 2500–2800
Prichard formation		Dark-gray sandy argillite. Weathers rusty brown. Some beds slightly calcareous. Minor amounts of light-colored sandstone and quartzite, that become more abundant near the top. 9700+	Dark-gray thin-bedded sandy argillite. Weathers rusty brown. Interbedded gray sandstone near top. 7800+

The Libby and Trout Creek quadrangles are underlain for the most part by Belt rocks, chiefly argillite, shale, sandstone, quartzite, and, to a less extent, dolomite and dolomitic limestone, with a total thickness of about 44,000 feet. Throughout both quadrangles four stratigraphic units

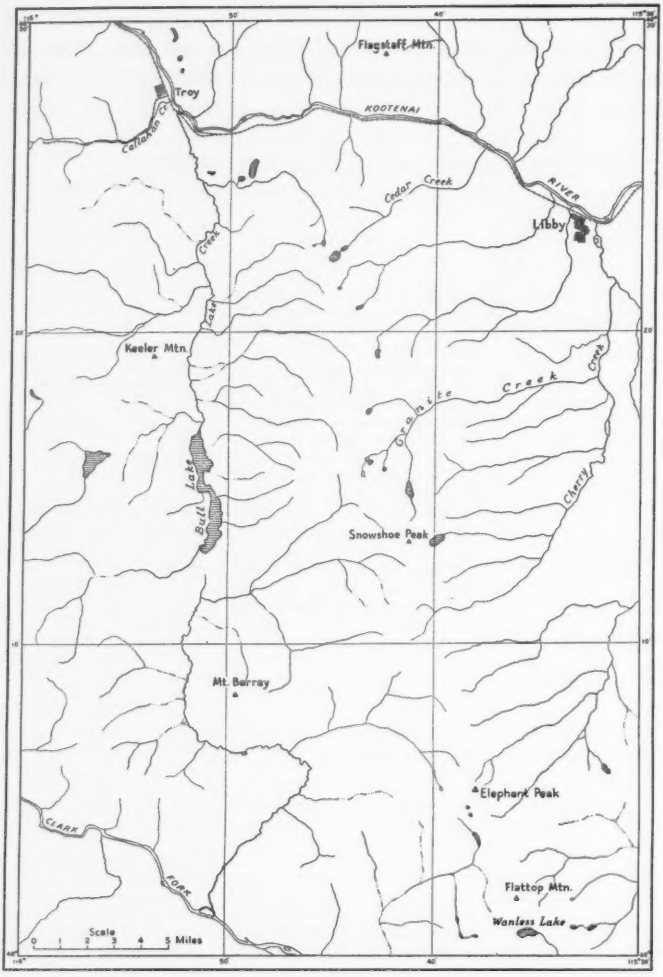

FIGURE 2.—*Locality map of the Libby quadrangle, Montana*

can be distinguished—the Prichard, Ravalli, Wallace, and Striped Peak. All except the Ravalli correspond with formations distinguished by Ransome and Calkins (1908, p. 23-25) in the Coeur d'Alene district. The Striped Peak has been divided into upper and lower members in the Libby quadrangle. Neither the bottom of the Prichard nor the top of the

Striped Peak is exposed in either quadrangle. A tabular section of these formations is given in Table 1 with thickness and brief descriptions for the Libby quadrangle and the central part of the Trout Creek quadrangle.

Intrusive rocks, described elsewhere (Gibson *et al.*, 1938) underlie not more than 4 per cent of the area.

Descriptions of the Belt rocks and notes on distribution which follow refer to exposures within the Libby quadrangle and that part of the Trout Creek quadrangle between the Libby quadrangle and the Coeur d'Alene district mapped during this survey (Pl. 1). The geologic map of the Libby quadrangle will be published in a forthcoming bulletin of the United States Geological Survey. A geologic map of most of the Trout Creek quadrangle is presented herewith (Pl. 1). Important localities in the Libby quadrangle referred to in this paper are shown in Figure 2.

ACKNOWLEDGMENTS

The Libby quadrangle was mapped for the United States Geological Survey. The mapping of part of the Trout Creek quadrangle was an independent project undertaken by Jenks to help correlate the Belt rocks of northwestern Montana with those in the Coeur d'Alene district of Idaho. The writers were assisted in the field by P. C. Henshaw, O. W. Jarrell, C. B. Moke, J. H. Moses, R. P. Sharp, R. H. Svendsen, and A. W. Waldo. Messrs. G. F. Loughlin and J. T. Pardee of the Survey furnished helpful guidance in the field and in the preparation of the manuscript. Professors P. E. Raymond and M. P. Billings of Harvard University critically read the manuscript. Mr. E. A. Schmitz aided in draughting the maps.

Grants from the California Institute of Technology and from the Milton Fund at Harvard University helped finance the project.

BELT SERIES

PRICHARD FORMATION

The largest area of Prichard in the Libby quadrangle is in the northwestern part, west of the Lenia fault and north and south of Callahan Creek. Another large area east of the Snowshoe fault and south of Cherry Creek extends uninterruptedly southeastward into the Trout Creek quadrangle. The largest exposure in the latter, where the Prichard forms the core of an anticline crossing Trout Creek, is north of the northeastern corner of the Coeur d'Alene district.

The thickness of the Prichard in the Coeur d'Alene district (Ransome and Calkins, 1908, p. 25) is at least 8000 feet; in the Libby quadrangle, at least 9700 feet. The bottom is not exposed in either area.

Little variation from the lithology of the typical Prichard is evident throughout the area. Dark-gray argillite which weathers to a rusty brown makes up most of the Prichard; interbedded light-colored sandstone and quartzite are quantitatively less important. Toward the top, the beds become sandier and lighter in color, but there is no well-defined contact zone of the Prichard and the Ravalli. The boundary is in the middle of a zone from 200 to 700 feet thick in which gray sandstone becomes increasingly abundant upward.

Thin sections reveal the Prichard to be in places highly siliceous with abundant clastic quartz grains in a cement now largely sericitic. Chloritic material is relatively scarce. Casts of gypsum crystals approximately 0.5 cm. or less in greatest dimension are a characteristic but infrequent feature of the bedding planes of the finer-grained facies of the Prichard.

Certain minor differences between the Prichard of the type locality and that in the Libby and Trout Creek areas are noted. Slaty cleavage is less conspicuous in the Libby and Trout Creek quadrangles than in the Coeur d'Alene district. For the most part it is only very locally developed, as for example, in the zone adjoining some of the major faults. In the Libby and Trout Creek areas, the Prichard is somewhat calcareous, whereas no lime carbonate is reported in the Prichard of the Coeur d'Alene.

RAVALLI GROUP

The Burke, Revett, and St. Regis formations distinguished by Calkins in the Coeur d'Alene district are easily recognized units there. They can be traced as far north as Lost Peak in the Bitterroot Range, Trout Creek quadrangle, but farther north and northeast the boundaries between the three formations gradually become less distinct. North of the Clark Fork in the Cabinet Range it is difficult, if not impossible, to map them separately. In his work in northern Idaho and northwestern Montana, Calkins (1909, p. 37) adopted Walcott's term Ravalli to include the Burke, Revett, and St. Regis where they could not easily be mapped as individual units. He regarded these rocks as the equivalent of the Ravalli group in the Swan and Mission Range sections (Walcott 1899). Calkins' usage is followed in this paper.

The Ravalli rocks, being resistant, form bold outcrops (Pl. 3, fig. 2) and prominent talus slopes especially where the quartzitic middle part (Revett) is exposed. In the Libby quadrangle east of the Snowshoe fault and on the east limb of the Snowshoe anticline which trends southward to Flattop Mountain, the Ravalli is exposed for 20 miles in a narrow band from Granite Creek on the north to the southern boundary of the

quadrangle. In the western third of the quadrangle, from Goat Mountain on the north to Clark Fork on the south, are more extensive exposures on both limbs of northward-trending synclines. In the Trout Creek quadrangle the Ravalli crops out between Rock and Swamp Creeks northeast of Clark Fork and appears to be cut off on the south by the Hope Fault. South of the Clark Fork this formation is exposed along the East Fork of Trout Creek on both limbs of a northeastward-trending anticline which continues into the Coeur d'Alene district.

The Ravalli group ranges in thickness from 4200 feet in the Coeur d'Alene district (Ransome and Calkins, 1908, p. 25) to approximately 10,000 feet near Wanless Lake in the southeastern part of the Libby quadrangle. Toward the northwest the Ravalli again becomes thinner and on Keeler Mountain in the northwestern part of the Libby quadrangle it is only 7000 feet thick.

The Burke formation of the Ravalli group near the Coeur d'Alene district is composed of gray quartzite and sandstone, and of argillite similar to the Prichard. Farther north in the Libby quadrangle the beds are less arenaceous and more argillaceous. In the Coeur d'Alene district the Burke is 2000 feet thick; northward in the anticline along Trout Creek, it is 2500 to 2800 feet thick. In the Libby quadrangle the Burke cannot easily be separated from the Revett above and, hence, has not been mapped separately, but it appears to be much thinner than it is farther south.

The middle Ravalli, equivalent of the Revett, is dominantly massive hard even-grained white, locally crossbedded, quartzite. This is the most characteristic part of the Ravalli and in the Coeur d'Alene district, is "the simplest and most homogeneous of the Coeur d'Alene sediments" (Ransome and Calkins, 1908, p. 35). Individual beds are commonly 1 to 3 feet, rarely 10 to 15 feet thick. In places in the Libby quadrangle the quartzite contains small amounts of sericite, calcite, dolomite, or iron oxide. Wherever iron is present the beds exhibit reddish or purplish tints on weathered surfaces. Some of the quartzites are feldspathic, though rarely containing more than 10 per cent and never more than 20 per cent feldspar. The feldspar is largely orthoclase but some albite-oligoclase and a very little microcline are present. The original outlines of the thoroughly cemented quartz grains are usually distinguishable in thin sections. The grains are well sorted as to size, are largely subangular, and rounded grains even in the coarser beds are exceptional. Interbedded with the quartzite are gray argillaceous sandstone and sandy, sericitic shale and argillite. In the northern part of the Trout Creek quadrangle and the southern part of the Libby quadrangle argillaceous sandstone increases in amount. The shale and argillite in the

Libby quadrangle contain small amounts of calcium carbonate, iron oxide, or both.

A section of part of the Ravalli (about 5 miles southwest of Clark Fork on the ridge southwest of Minton Creek in secs. 28 and 29, T. 24 N., R. 32 W.) follows. This section was measured about 5 miles northeast of the last point where the three members of the Ravalli can be clearly differentiated. Farther north in the Libby quadrangle the hard white quartzite of the middle Ravalli (Revett) can be recognized in most places, but its boundaries are indistinct.

SECTION OF PART OF RAVALLI GROUP
Southwest of Minton Creek

Wallace formation
Conformable contact
Ravalli group:

	Feet
St. Regis formation:	
Gray, gray-green, and minor amounts of reddish shales showing mud cracks	1150
Gray-green shale and thin beds (2-3 inches) of hard white quartzite	50
Hard white quartzite and subordinate amounts of gray-green shaly sandstone	500
Revett (?) quartzite:	
Hard white banded quartzite	1150
Burke (?) formation:	
Interbedded white quartzite and gray shaly banded quartzite	1400
Total	4250

Base of Ravalli not exposed.

The St. Regis formation of the Ravalli is composed mainly of shale which in places is highly colored in shades of green and red and elsewhere is dull gray. Consequently, color alone does not distinguish the St. Regis from the strata above and below. The red color is most strongly developed in places in the Coeur d'Alene district and on the west fork of Trout Creek. Farther north and northeast the red and green shades become less pronounced, and north of the Clark Fork the shale is gray and becomes arenaceous, calcareous, and sericitic. In the Libby quadrangle, above this shale are thin beds of bluish-gray sandy argillite which are taken to be the top of the St. Regis, *i.e.*, the top of the Ravalli (Pl. 2, fig. 2).

The contact between the St. Regis and the Revett is distinct south and southwest of Lost Peak; in the opposite direction it is increasingly hard to determine. Near the base of the St. Regis southwest of Lost Peak appear numerous beds of pale-gray, green, or lavender quartzite as shown in the detailed section measured along the west fork of Lost Creek in sec. 13, T. 51 N., R. 4 E., Shoshone County, Idaho.

SECTION OF PART OF RAVALLI GROUP

West fork of Lost Creek, Trout Creek quadrangle

St. Regis formation:	Feet
Gray shale	1
White (faintly lavender) quartzite	0.5
White slightly shaly quartzite	5
Concealed	65
Light gray-green sandy shale	2
White hard quartzite	2
Greenish shaly quartzite	1
Gray-green shaly quartzite	20
White slightly shaly quartzite	10
Concealed	25
Faintly lavender and green thin-bedded sandy shale. Shows mud conglomerate and oscillation ripples	35
Green sandy massive shale	6
Lavender and green shale	12
Greenish and brownish spotted quartzite	3
Pale-gray massive shaly quartzite	6
Interbedded light-gray and green shaly quartzite	22
Total	215.5
Transition zone:	
White hard quartzite	1
Interbedded light-gray and green shaly quartzite	12
White hard cross-bedded quartzite with gray shale layers	12
Gray-green shaly quartzite	13
Interbedded white hard quartzite and gray-green shaly quartzite	20
Gray and gray-green shaly quartzite	72
Total	130
Revett quartzite:	
White hard quartzite	45
Concealed	20
Gray-green shale	2
White hard quartzite	1
Concealed	50
White hard quartzite	10
Total	128

WALLACE FORMATION

The term Wallace instead of Newland is used in this paper for the formation younger than Ravalli and older than the Striped Peak because it is continuous with the Wallace in the Coeur d'Alene district. Calkins, in his reconnaissance in northern Idaho and northwestern Montana (Calkins, 1909, p. 38) called this formation the Newland because he believed that it could be correlated with the Newland of the original Belt Mountains section and, hence, on the grounds of priority should receive that name. As there is some doubt of this correlation and as the term Wallace has been used in recent years for the corresponding formation in the near-by Clark Fork (Anderson, 1930, p. 17) and Pend Oreille

(Sampson, 1928, p. 7) as well as in the Coeur d'Alene and Missoula (Clapp and Deiss, 1931) districts, that name will be used in this paper.

The Wallace underlies most of the northwestern part of the Trout Creek quadrangle and is exposed on both limbs of the Trout Creek anticline in the central part of that area. This formation comprises the most abundant surface rock of the high mountains in the central part of the Libby quadrangle, underlying Snowshoe (Pl. 2, fig. 1) and A Peaks, the highest points, and is well exposed north and south of these peaks between Snowshoe fault and Lake Creek valley.

Along Big Creek (Pl. 1) 3 miles north of the Coeur d'Alene district about 7000 feet of Wallace is exposed, whereas Calkins estimated 4000 feet in the Coeur d'Alene district (Ransome and Calkins, 1908, p. 25). Northward and northeastward from Big Creek the Wallace thickens rapidly. Along the southwest side of Clark Fork between Huckleberry Mountain and Trout Creek the formation is 10,500 feet thick; near Mount Berray in the Libby quadrangle, 12,500 feet; and on the long west ridge of Snowshoe Peak, at least 16,500 feet. Plate 3, figure 1, a photograph of this ridge, most of which was traversed, illustrates the uniform westerly dip and absence of structural irregularities. In the northeastern part of the Libby quadrangle the formation appears to be approximately 17,000 feet thick.

In the Libby and Trout Creek areas as well as in the Coeur d'Alene district the Wallace is the most heterogeneous formation of the Belt series. It is the most difficult to identify with certainty. Beds similar to those in every other formation may be duplicated in the Wallace. Argillite and shale are dominant; sericitic sandstone and quartzite are much less common; dolomite and dolomitic limestone are present but are more abundant in the Trout Creek than in the Libby quadrangle. The argillaceous and arenaceous beds are characterized by small quantities of calcium and magnesium carbonate in many places, but these carbonates are, seemingly, not so widespread or so abundant as they are in the Coeur d'Alene district. The most common single type of rock in the Wallace is a light-gray to greenish-gray, buff-weathering sandy shale or argillite which is usually calcareous or dolomitic and slightly ferruginous. Locally, red beds similar to the lower part of the Striped Peak are present near the top of the formation.

In the Libby quadrangle limestone and dolomite are found in thin beds at several horizons, and almost invariably in association with the red beds near the top of the Wallace. In the Trout Creek quadrangle limestone and dolomite are especially abundant in a zone about 1000 feet thick which begins 1200 to 2000 feet above the base. Here the carbonate

FIGURE 1. SNOWSHOE PEAK, UNDERLAIN BY WALLACE FORMATION
Photograph by K. D. Swan, courtesy U. S. Forest Service.

FIGURE 2. ST. REGIS-WALLACE CONTACT
East fork (left foreground) and West Fork (center) of Trout Creek, Trout Creek quadrangle. Contact follows top of highest line of cliffs just to right of center of picture. (Photograph by 116th Photo Section, Washington National Guard.)

SNOWSHOE PEAK AND ST. REGIS-WALLACE CONTACT

FIGURE 1. WESTWARD-DIPPING WALLACE FORMATION
Western ridge of Snowshoe Peak, Libby quadrangle.

FIGURE 2. WESTWARD-DIPPING RAVALLI GROUP
Elephant Peak, Libby quadrangle.

strata are dark gray to black, buff-weathering and thick-bedded, characterized partly by the peculiar "molar-tooth" structures described by Bauerman (1885, p. 26) and by Daly (1912, p. 73-77) from the Siyeh and Kitchener formations along the international boundary. These structures were observed in no other Belt formations in the Libby and Trout Creek quadrangles. Similar "molar-tooth" beds illustrated by Rice (1937, Pl. 2A) are "Diagnostic of the Kitchener" in the Cranbrook map area of British Columbia. The Kitchener has been correlated with the Wallace. The "molar-tooth" beds are similar to the cellular ones described and illustrated by Anderson (1930, p. 18) who found them characteristic of the Wallace in the Clark Fork district. Anderson does not use the term "molar-tooth," however.

Thin beds, described by Walcott (1915) and more recently by Fenton and Fenton (1931, 1933) as algal limestone or dolomite, are present in the Wallace at several horizons, especially in the northern half of the Libby quadrangle. One of the excellent exposures is at Kootenai Falls. Algal beds are almost invariably present in the red shaly strata near the top of the Wallace but their distribution elsewhere in the formation is erratic. Algal dolomite is found also in the lower part of the Striped Peak where it is associated with red sandy beds. Doubt has been expressed about the organic origin of the so-called algal limestone and dolomite but a discussion of the matter is beyond the scope of this paper.

The Wallace formation, even where it is thickest, could not be subdivided. Individual beds change rapidly in lithology along the strike so that no distinctive beds persist.

The following section was compiled from several measured between Huckleberry Mountain and Trout Creek, Ts. 24 and 25 N., and Rs. 32 and 33 W. and shows the lithology of the Wallace in this area.

SECTION OF WALLACE FORMATION

Between Huckleberry Mountain and Trout Creek, south of the Clark Fork

Striped Peak formation:
Red and green shale

Wallace formation:	Feet
Gray-green shale	1400
Buff-weathering, paper-thin, calcareous shale	200
Gray shale and shaly limestone	700
Light gray-green shale; a few beds are calcareous	1350
Metadiorite sill	75
Gray-green sandy shale	275
Gray shale	400
Interbedded, finally laminated, light-gray quartzite and gray shale	100
Gray-green calcareous argillite	700

	Feet
Pale yellowish-gray paper-thin shale	200
Gray banded shale; weathers gray green	250
Gray calcareous shale, calcareous sandstone, and thin-bedded dense dolomitic limestone	1050
Gray thin-bedded shale	700
Medium- to dark-gray dolomitic limestone and calcareous shale	550
Dark- and light-banded shaly limestone	200
Gray shale and limestone interbedded with gray hard quartzite	100
Gray, buff-weathering limestone	200
Medium- to dark-gray shale and calcareous sandstone	250
White hard quartzite and gray shaly sandstone, some beds calcareous	550
Gray-green banded siliceous argillite	500
Gray-green calcareous and sandy shale	600
Total Wallace formation	10,350

Ravalli group:

Green and deep-red micaceous, sandy shale

STRIPED PEAK FORMATION

The Wallace formation is conformably overlain by the Striped Peak, named by Calkins for a mountain in the Coeur d'Alene district. Only along Kootenai River in the Libby quadrangle are there large exposures of the Striped Peak in the areas being discussed. A few remnants are present in synclines on high peaks, however.

In the Coeur d'Alene district (Ransome and Calkins, 1908, p. 25) 1000 feet of the Striped Peak is exposed, whereas in the northern part of the Libby quadrangle a thickness of 8000 feet has been measured. The top is not exposed in any of the three areas under discussion.

The Striped Peak was divided into two members in the Libby quadrangle. The lower member, 2000 feet thick, is the most homogeneous group of beds in either the Libby or Trout Creek areas. This member can easily be distinguished from the Wallace below and the upper member of the Striped Peak above. Dark-red to purplish sandstone and quartzite characterize the lower member of the Striped Peak in the northern part of the Libby quadrangle, but southward the beds become more shaly, and greenish strata appear. Algal beds, described below, are present but quantitatively unimportant.

The Striped Peak of the Coeur d'Alene district is similar to the lower member of the Striped Peak in the southern part of the Libby quadrangle and in the Trout Creek area, but no algal beds are reported from the Coeur d'Alene district. The sandy and quartzitic beds of the Striped Peak formation are usually somewhat more feldspathic than those of the Ravalli; the degree of sorting and rounding of grains is, however, similar. Ferruginous cement is much commoner in the Striped Peak than in the Ravalli. The following section was measured on Mt. Berray in the southern part of the Libby quadrangle.

GENERALIZED SECTION OF LOWER MEMBER OF STRIPED PEAK
Mount Berray in southern part of Libby quadrangle

Lower member of Striped Peak formation:	Feet
Top not exposed	
Green sandy, micaceous shale	150
Interbedded green and red sandy shale	300
Thin-bedded, red and green shale; some layers show casts of salt crystals	250
Interbedded red shale, red sandstone, and algal limestone	300
Green medium-bedded shaly quartzite	50
Red shale and shaly sandstone	550
Red and gray-green micaceous shale and shaly sandstone	300
Red shale	100
Total	2000
Wallace formation:	
Gray-green, thin-bedded shale	

The upper member of the Striped Peak has no equivalent in the Coeur d'Alene district. The commonest rock of this member in the Libby and Trout Creek areas is a light- to dark-gray and greenish-gray argillite, usually somewhat sandy and to a less extent sericitic and calcareous. The beds are mainly 1 to 3 feet thick. Some exhibit very thin light- and dark-colored laminae, many of which, resembling the Prichard, are ferruginous and weather rusty brown. But beds resembling the Prichard were not observed in large volume anywhere in the Striped Peak. Thin-bedded gray sandstone, thin-bedded dark-gray oölitic ferruginous, magnesian limestone, and white algal dolomite are less abundant in the upper member. Below is a generalized section of the lower part of this member exposed on the south side of Kootenai River southeast of Flagstaff Mountain.

GENERALIZED SECTION OF LOWER PART OF UPPER MEMBER OF STRIPED PEAK
South side of Kootenai River southeast of Flagstaff Mountain

Upper member of the Striped Peak:	Feet
Top not exposed.	
Thin-bedded gray argillite laminated alternately dark and light.	
Thin-bedded gray sericitic argillite. Weathers brown.	
Thick-bedded dark-gray argillite	400
Partly covered. Partly gray sand argillite and dark-gray shale	900
Thick-bedded dark-gray argillite and thin-bedded light-gray shales which weather brown	150
Thinly laminated drak-gray shale; gray sericitic argillite; and dark-gray ferruginous, magnesian limestone, in part oölitic and in part carbonaceous	300
Thick-bedded argillite laminated alternately dark and light. Weathers brown.	
Olive-green sericitic argillite. Weathers brown and greenish-gray.	
Calcareous sandstone.	
Dark-gray and greenish sericitic, calcareous argillite in well-jointed beds as much as 2 feet thick. Weathers brown	500
Total	2250
Lower member of the Striped Peak	

Algal dolomitic limestone and dolomite are more widespread in the Striped Peak than in the Wallace and are typically associated with red shale but are so erratic in distribution they cannot be used as horizon markers. At several localities oölitic, dolomitic limestone is interbedded with concretionary algal beds. The latter strongly resemble certain of the colonies figured by Fenton and Fenton (1933) from the Siyeh of Glacier Park. Calkins reports no beds of this description from the Coeur d'Alene district.

In the following section measured on the east slope of Little Guard Peak in the central western part of the Trout Creek quadrangle no distinction can be made between the two members of the Striped Peak.

SECTION OF PART OF STRIPED PEAK FORMATION

Little Guard Peak, 10 miles north of the Coeur d' Alene district, Idaho

Striped Peak:

Top not exposed.

	Feet
Thick-bedded purple and green quartzite	100
Interbedded red and green shale and banded algal dolomitic limestone	50
Concealed	100
Pink and green micaceous shaly quartzite	50
Conceled	300
Red shale	400
Concealed	500
Gray quartzite tinged green and lavender, and red shale	400
Concealed	200
Pinkish and purplish shale	100
Hard green quartzite with minor amount of thin-bedded gray shale	50
Red sandy shale, and pinkish-gray shaly quartzite	50
Red and green shale and shaly sandstone	200
Red shale	50
Red shale and shaly quartzite	500
Total	3050

Wallace formation:

Gray-green, buff-weathering shale

SHALLOW-WATER ORIGIN OF THE BELT SERIES

All the Belt formations in the Libby and Trout Creek quadrangles exhibit sun cracks, ripple marks, and cross-bedding. These features are best developed in the Wallace and least conspicuous in the Prichard. The Wallace shows also a few casts of salt crystals. These evidences of the shallow-water origin of the Belt rocks have been emphasized by other workers (Ransome and Calkins, 1908; Walcott, 1910; Rice, 1937; Fenton and Fenton, 1937) and confirm the conclusion that the Belt sediments were probably deposited in a broad, shallow, epeiric sea or lake, the bottom of which was continually being unevenly depressed. From time to time wide areas of mud flats were exposed. In places great

shallow pools were isolated by slight depressions in the plains of mud and sand, where undoubtedly the waters became brackish. As Calkins (1908, p. 72) points out, there is no evidence to show whether the carbonate

TABLE 2.—*Correlation of principal sections of Belt series*

In northwestern Montana and northern Idaho.

(Measurements in feet)

Formation	Coeur d' Alene district, Idaho*	Clark Fork district, Idaho†	Pend Oreille district, Idaho**	Trout Creek quadrangle	Libby quadrangle	Boundary County, Idaho, east of the Purcell trench††
Striped Peak	1000+	4000+	9000+	3700+	Upper Member 6000+ Lower Member 2000+	
Wallace	4000	6000	6000	10,500	16,500	Kitchener-Newland-Wallace 4500+
St. Regis	1000	7500	Blacktail 8300	Ravalli 4700–5700	Ravalli 7000–10,000	Creston-Ravalli 5000+
Revett	1200	Burke 3500				
Burke	2000		Burke 2000+			
Prichard	8000+	20,000+	7000+	7800+	9700+	Aldridge-Prichard 10,000+

* Ransome, F. L., and Calkins, F. C. (1908).
† Anderson, A. L. (1930).
** Sampson, Edward (1929).
†† Kirkham, V. R. D., and Ellis, E. W. (1926).

in these formations was furnished by organisms or had been precipitated by evaporation. Excepting the algal beds of the Wallace and Striped Peak, fossils were not found in the Belt rocks of the Libby and Trout Creek areas.

CORRELATION

Table 2 gives a correlation of the Belt formations in northwestern Montana and northern Idaho. The formations have been mapped in detail on topographic sheets of the United States Geological Survey from

the Libby quadrangle on the north through the Trout Creek quadrangle to the northern part of the Coeur d'Alene district. In these three areas the formations are continuous and the correlations are reasonably certain. An area about 2 miles wide between the Libby quadrangle in Montana and the Clark Fork district in Idaho has not been studied.

Correlations with the Belt rocks in the Pend Oreille district, Idaho, and in Boundary County, Idaho, are more speculative. The Pend Oreille-Coeur d'Alene correlation agrees with Sampson's (1929) interpretation, and the Boundary County-Coeur d'Alene correlation agrees with that of Kirkham and Ellis (1926, p. 21-27). Kirkham and Ellis do not differentiate the various Belt formations on their reconnaissance geologic map of Boundary County, Idaho, but they describe the different formations and submit correlations with other Belt areas.

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OSTRACODES OF THE MIDDLE DEVONIAN ONONDAGA BEDS OF CENTRAL PENNSYLVANIA

BY FRANK M. SWARTZ AND FREDERICK M. SWAIN

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ABSTRACT

Collections from the Middle Devonian Onondaga shale and limestone of central Pennsylvania and northeastern West Virginia have provided an abundance of Ostracoda, and the field work has also yielded much information concerning the lithologic features and the relationships of the Onondaga deposits. Descriptions are given of the Onondaga beds observed at 12 localities in Pennsylvania and 2 in West Virginia, and the stratigraphy as seen at these places is discussed.

A total of 40 ostracode species has been recognized in the area. Of these, 3 were previously described, 35 are new, and 2 are represented by material too poor for specific description. The species are distributed through 11 families and 22 genera, 3 of the latter being new. For comparisons with members of this fauna, new figures and descriptions are given of 3 species from the Jeffersonville limestone of Kentucky, and of 1 from the Hamilton shale of Ontario.

Four ostracode zones are recognized in the Onondaga beds near New Bloomfield, Pennsylvania. One of these is widespread; further work is needed to indicate the geographic distribution of the other three. The assemblage as a whole is not close to the known ostracodes of the Onondaga of New York, but further study of the latter will be needed before trustworthy conclusions can be drawn. The ostracodes of the Onondaga of Pennsylvania are clearly distinct from those of the Jeffersonville limestone of Kentucky, suggesting an appreciable difference in age. There are important affinities with ostracodes of the Camden chert of western Tennessee as recently studied by Bassler, but the latter assemblage includes numerous Oriskany elements and is clearly older.

INTRODUCTION

In central Pennsylvania and southward through Maryland into nearby parts of the Virginias, the Lower Devonian Ridgeley sandstone, containing the *Spirifer arenosus—Hipparionyx proximus* fauna characteristic of the Oriskany of New York, is commonly overlain by about 100 feet of calcareous shale and impure limestone. This is followed in turn

by Marcellus black shale. Subsequent to the noteworthy work of Kindle (1912) the calcareous shale and impure limestone have been regarded as a southern and more argillaceous facies of the Onondaga limestone of New York and have been included in the Onondaga formation (Kindle, 1913; Swartz, 1912; 1913; Butts, 1918; Willard, 1936; 1939). This correlation has been based on stratigraphic position and, more importantly, on the occurrence in the shale and shaly limestone of important Onondaga brachiopod and especially trilobite species.

The presence of ostracodes in the Onondaga beds of Pennsylvania has long been known. Over 50 years ago, on the basis of collections obtained by Claypole, two species were described by Jones (1889) from "buff shale of the Marcellus limestone" near New Bloomfield, Pennsylvania. Six species were subsequently figured and described by Kindle in 1912 and were cited by him as evidence of Onondaga age. *Bollia ungula* Jones was refigured and discussed by Swartz in 1936.

The present studies have brought to light a further wealth of ostracodes, providing much new information concerning the previously cited forms, and leading to the discovery of a considerable number of new species and three new genera. In all, 40 species—35 of them new—are described from the Onondaga beds of the area, and four species of the Jeffersonville limestone of Kentucky and Hamilton shale of Ontario are refigured and discussed for purposes of comparison. (*See* Table 1.) The exposures seen at the localities from which the collections were obtained are described on the next following pages, together with a summary of the stratigraphic features of the deposits. The stratigraphic significance of the ostracodes is then discussed, and the species are described.

ACKNOWLEDGMENTS

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vided by the School of Mineral Industries of the Pennsylvania State College.

STRATIGRAPHY OF ONONDAGA DEPOSITS AND DESCRIPTION OF SECTIONS

STRATIGRAPHY OF THE ONONDAGA DEPOSITS

During work on the ostracodes which proved to be so abundant in the Onondaga deposits of central Pennsylvania, a considerable amount of information has been gathered with respect to the thicknesses, lithologic features, and relations of the Onondaga beds of the area. No attempt has been made to systematically complete this phase of the investigation, or to study the nonostracode faunules; but the general results so far obtained will be summarized, and more detailed accounts will be given by descriptions of the local sections.

The localities visited, and the stratigraphic relations of the deposits exhibited both at certain of these places and in neighboring areas are indicated in Figures 1 and 2. Swain procured material from Lewistown, McVeytown, Lock Haven, Warren Point, and Swatara Gap, Pennsylvania, and studied it for a Master's thesis at The Pennsylvania State College. Charles Butts donated specimens from Cooper Mountain, West Virginia, and Bradford Willard supplied part of the material from New Bloomfield. Swartz obtained collections from New Bloomfield, Clarks Mill, and Newton Hamilton, Pennsylvania, and from Berkeley Springs, West Virginia; he has also described Onondaga sections at Jackson Corner, Martin Gap, Hollidaysburg, and Tyrone, Pennsylvania. The work done has yielded information concerning both Onondaga ostracodes and sequences over a fairly extensive area.

At Swatara Gap, the most easterly section from which ostracodes were obtained, the Onondaga beds are somewhat argillaceous limestones, only 20 feet in thickness. As shown by C. K. and F. M. Swartz (1931) the limestones are underlain by Inwood sandstone of late Silurian age and are overlain by Marcellus black shale. The Marcellus is also persistent above the Onondaga at the other studied localities, but the Onondaga beds become more shaly, are thicker, and are underlain by the Ridgeley sandstone of the Lower Devonian Oriskany group. The Onondaga beds are about 100 to 105 feet thick at New Bloomfield, in east central Pennsylvania, and are about 120 to 130 feet thick at Newton Hamilton, Lewistown, and Martin Gap nearer the center of the state. They decrease to about 80 feet at the foot of the Allegheny Front near Tyrone, along their most westerly crop in Pennsylvania. Farther northeast along this belt, Butts and Moore (1936) and Willard (1939) have reported that the Onondaga formation may be missing across parts of Centre and

Clinton counties. However, about 10 feet of limestone probably referable to the Onondaga was found near Lock Haven in Clinton County; the distance of this limestone above the Oriskany is uncertain but may be around 25 to 50 feet. At the Maryland line, the Onondaga beds are

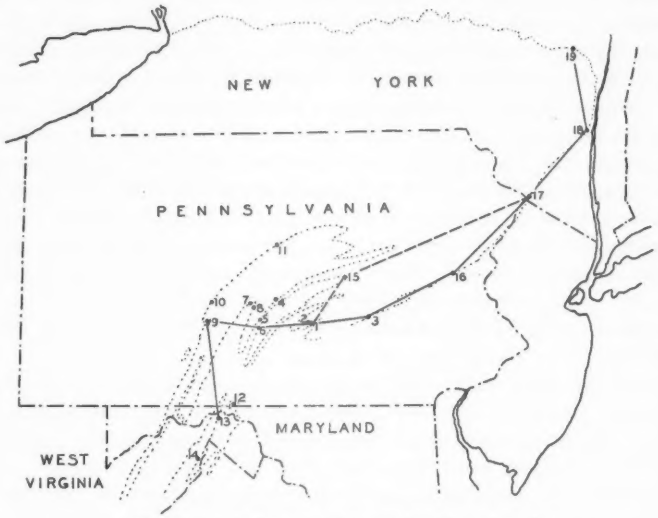

FIGURE 1.—*Index map showing location of sections*

Studied or examined during this investigation (1-14), and of sections with which comparisons are made in Figure 2 (15-19). Dotted lines show belts of Onondaga outcrop; solid and dashed lines connect sections shown in Figure 2. (1) New Bloomfield; (2) Clarks Mill; (3) Swatara Gap; (4) Mount Rock, Lewistown; (5) McVeytown; (6) Newton Hamilton; (7) Jackson Corner; (8) Martin Gap; (9) Frankstown, near Hollidaysburg; (10) Tyrone; (11) Lock Haven; (12) Warren Point; (13) Berkeley Springs; (14) Cooper Mountain; (15) Selinsgrove; (16) Little Gap, near Palmerton; (17) Trilobite Mountain; (18) Kingston; (19) Schoharie Valley.

about 115 feet thick near Warren Point, Pennsylvania; some miles farther south at Berkeley Springs, West Virginia, they are about 110 feet thick.

The Onondaga beds of central and south central Pennsylvania consist for the most part of calcareous shales and argillaceous limestones. As was recognized locally by White (1889) and then more generally by Kindle (1912) and Willard (1936, 1939) the impure limestones are more abundant in the upper beds and are less important below; also, toward the south and southwest they apparently tend to decrease somewhat in proportion to the shale. On this basis, Willard (1939) has recently proposed to divide the Onondaga beds of central Pennsylvania into Selinsgrove limestone, above, and Needmore shale, below, these

bodies corresponding in a general way to the Selinsgrove lower limestone and Selinsgrove shale of White.

It will probably prove desirable to use one or more local names for the argillaceous Onondaga sediments seen in central Pennsylvania and farther south. However, the attempt to divide these deposits into two members has not been placed as yet on a sound basis. In fresh cuts, as in the quarry at Half Falls Mountain figured by Willard (1939, Fig. 32), the railroad embankment at Newton Hamilton, and the road cut at Jackson Corner, the upper part of the formation appears to contain a large proportion of limestone. In less complete and more weathered exposures the limestones in part tend to break down into more argillaceous appearing material, and separation of the more shaly and more limy portions is not very satisfactory. Even in the finely displayed section near Newton Hamilton there has been confusion in the application of the two names. More importantly, before the term "Needmore shale" can be satisfactorily evaluated some description is needed of its sequence, faunas, and relationships in its type area. (*Cf.* Willard, 1939, p. 343.)

An interesting feature of the upper beds is the appearance at Jackson Corner and near Tyrone of layers of limestone coquinite containing in profusion the shells of small brachiopods and some questionable pelecypods. The shells are commonly 2 or 3 to 5 mm. in diameter, and impart a peculiar texture to the beds, especially where the shells are less well preserved and the shelly nature of the rock less obvious. Some limestones of this type were also found near Lock Haven. At both Tyrone and Jackson Corner, the abundant forms tend to differ from layer to layer and may have zonal value. In some beds there is a profusion of small Ambocoelias with strong sinus and weak costae; in others a smoothly convex *Meristella (?)* is the most abundant. *Strophalosia truncata* and *Productella* sp. occur more sparingly. These coquinites seem to be a more westerly facies and were not observed in the cut at Newton Hamilton, although another search should be made there for them. Their age and faunas need further investigation.

One of the interesting problems connected with the Onondaga beds concerns the possible interfingering with black shales of Marcellus type. In general, the shales of the Onondaga in central Pennsylvania are seen in a more or less weathered condition and are then gray to greenish in color. Willard (1939) has recognized that the greenish color is developed by weathering of beds which are medium to dark gray. He reports, however, a 78-foot thick body of black shale "very like the Marcellus" in the Onondaga at Newton Hamilton, and has proposed for it the name "Beaver Dam black shale." Kindle (1912) reported

black fissile shale 10 to 30 and 10 to 42 feet above the base of the Onondaga in two sections near Hollidaysburg. Black blocky shales have been reported in the Onondaga near Cumberland, Maryland (Kindle, 1913).

The shales at Newton Hamilton are indeed very dark gray grading to black as seen in the freshest exposures in the cut. They are, however, calcareous and, as can be seen at the top of the cut and in a second, near-by section, tend to break into small fragments and to become gray to greenish after a degree of exposure which leaves Marcellus fragments relatively firm and black except for a little surface or marginal discoloration. Blackish calcareous shales interbedded with the upper limestones of the Onondaga near Jackson Corner and Tyrone also become gray to greenish-gray after moderate weathering, so far as could be determined, and no black shale of Marcellus type could be found in the Onondaga near Hollidaysburg. A foot of fissile shale, still black after considerable exposure, is seen in the Onondaga north of Berkeley Springs, West Virginia. The western Maryland localities at which black shales have been reported in the Onondaga have not been examined by the writers.

The very dark-gray to black color of some of the Onondaga shales when fresh is of much interest in connection with subsurface geology and conditions of Onondaga sedimentation. Where these beds weather readily to gray and greenish colors, they differ markedly from black shales of Marcellus type, and it seems to the writers undesirable to speak of them as black shale members. The significance of such shales with regard to change toward a Marcellus-like facies is not clear.

The Marcellus—Onondaga contact is well exposed at only one of the localities examined; namely at the section near Tyrone. At this place the change from the one formation to the other is rather well defined, although a few thin very impure limestones occur in the basalmost Marcellus. The writers have not seen this contact enough to be confident about its nature. Willard (1939, p. 148), however, reports that "in part of central Pennsylvania, it is not uncommon to find the Marcellus—Onondaga contact disconformable."

The Onondaga—Oriskany contact is well exposed at five of the sections: namely, at Warren Point, New Bloomfield, McVeytown, Newton Hamilton, and Frankstown near Hollidaysburg. The boundary is persistently disconformable as has long been recognized. Insofar as the Onondaga of central Pennsylvania actually corresponds in age to the post-Esopus Onondaga of southeastern New York (*see* Fig. 2) the pre-Onondaga disconformity of the area here studied corresponds in value to the 300 to 500 feet or more of Esopus of the Trilobite Mountain and Kingston sections, together with any associated breaks. The whole question of relative age of the Onondaga of central Pennsylvania and

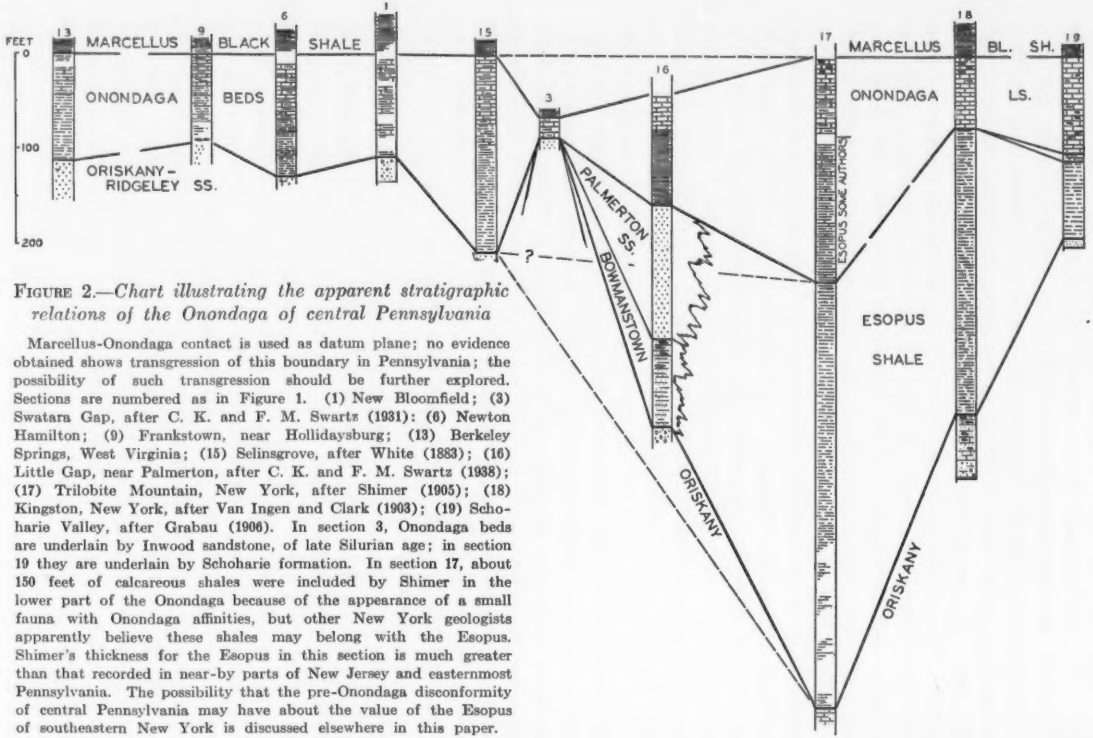

FIGURE 2.—*Chart illustrating the apparent stratigraphic relations of the Onondaga of central Pennsylvania*

Marcellus-Onondaga contact is used as datum plane; no evidence obtained shows transgression of this boundary in Pennsylvania; the possibility of such transgression should be further explored. Sections are numbered as in Figure 1. (1) New Bloomfield; (3) Swatara Gap, after C. K. and F. M. Swartz (1931): (6) Newton Hamilton; (9) Frankstown, near Hollidaysburg; (13) Berkeley Springs, West Virginia; (15) Selinsgrove, after White (1883); (16) Little Gap, near Palmerton, after C. K. and F. M. Swartz (1938); (17) Trilobite Mountain, New York, after Shimer (1905); (18) Kingston, New York, after Van Ingen and Clark (1903); (19) Schoharie Valley, after Grabau (1906). In section 3, Onondaga beds are underlain by Inwood sandstone, of late Silurian age; in section 19 they are underlain by Schoharie formation. In section 17, about 150 feet of calcareous shales were included by Shimer in the lower part of the Onondaga because of the appearance of a small fauna with Onondaga affinities, but other New York geologists apparently believe these shales may belong with the Esopus. Shimer's thickness for the Esopus in this section is much greater than that recorded in near-by parts of New Jersey and easternmost Pennsylvania. The possibility that the pre-Onondaga disconformity of central Pennsylvania may have about the value of the Esopus of southeastern New York is discussed elsewhere in this paper.

of New York needs review, especially in the light of any information which further ostracode studies can contribute to the better known evidence of other faunal elements. It is possible that the Onondaga of central Pennsylvania may include some beds of Esopus age, especially where it thickens toward the Selinsgrove area (Fig. 2, section 15). Willard (1939, p. 154), indeed, has rather positively correlated his "Needmore shale" with the Esopus, partly because of stratigraphic position, and partly because (p. 155) "their respective faunas appear identical save for relative abundance." Willard's faunal lists (p. 156-160) show little resemblance between the Esopus and "Needmore" assemblages. Over 55 identified species are recorded from the "Needmore"; of these, only 3 are represented among the 7 species cited from the Esopus,[1] and 2 of the 3 are found in post-Esopus Onondaga or younger beds. On the other hand, around 45 of the "Needmore" species are known in post-Esopus Onondaga or younger deposits in New York, and include a large proportion of the species which Kindle regarded as specially indicative of Onondaga age. Actually, the dissimilarities between these faunas as known are of rather negative value, because of the meagerness of Esopus species. More significantly, however, C. K. Swartz in 1913 pointed out the high percentage of Marcellus and Hamilton elements in the Onondaga of Maryland, and suggested that the observed faunas favor a late rather than an early Onondaga age for the Maryland beds, although the problem is complicated by facies differences.

The disconformable nature of the post-Oriskany surface at Warren Point, Pennsylvania, was recognized 40 years ago by Rowe (1900), who reported Oriskany-derived pebbles at this locality in the basal layers of the shales now included in the Onondaga. Similarly, sand and gravel evidently acquired from the underlying conglomeratic Oriskany are observed in the basal shales of the Onondaga at New Bloomfield. At Newton Hamilton, the top of the Oriskany sandstone is sharply marked and is overlain by several inches of sand mixed with a clayey matrix. At Frankstown near Hollidaysburg there is 1½ feet of chert close to the base of the Onondaga; the sand grains and perhaps the chert matrix as well were likely derived from the weathered upper surface of the Oriskany in adjacent areas. This same chert body is seen at the base of the Onondaga near Tyrone, and there weathers in part to iron-rich material. A red iron ore zone is also reported by Kindle at the base of the Onondaga about 4 miles east of Hollidaysburg, and there is a 3-foot zone of red-weathered clay at the base of the Onondaga

[1] Most of the identified species cited by Willard from the Esopus appear to be from the list of fossils of the Esopus-age Bowmanstown formation, supplied by C. K. and F. M. Swartz. The only "Needmore" species known from the Esopus proper seems to be the Onondaga *Anoplotheca acutiplicata* (Goldring, 1935, p. 135).

near Berkeley Springs. Singewald (1911) concluded that the iron ores of the basal Onondaga (Romney) of Maryland have formed by reaction between iron-bearing ground waters and the limestone layers. The possible presence of iron carbonate in the original sediments, as in the paint ore of the Onondaga near Palmerton, Pennsylvania (Miller, 1911), needs further investigation.

The stratigraphic features which have been summarized above are presented more objectively and in greater detail in the following section descriptions.

NEW BLOOMFIELD

The collections from New Bloomfield, Pennsylvania, are of special interest because they come from the approximate locality where Claypole found the ostracodes described by Jones in 1889. Furthermore, in conjunction with material from near-by Clarks Mill, they provide the most complete sequence of ostracode faunules so far obtained from the Onondaga beds of the Appalachian region. The exposures are seen at the Eckerd quarry in the Oriskany sandstone and along the adjacent bank of the former Susquehanna and Western Railroad, about three-tenths of a mile southeast of the New Bloomfield village square in the area of the New Bloomfield quadrangle.

Some loose material from this locality was collected by Bradford Willard in 1931 and was subsequently donated to the authors. Larger collections containing the same ostracodes were obtained in place about 25 to 30 feet above the base of the Onondaga by Swartz in 1938. Additional collections were obtained by Swartz during a more thorough study in 1940. The Oriskany beds were measured by ruler; the Onondaga was measured by traverse, beginning along the projected Oriskany–Onondaga contact about 100 feet east of the road leading past the quarry crusher, then extending southeast to and along the old railroad bank, crossing the beds in ascending order. Bearings are magnetic.

	Thickness in Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale; full thickness not determined. Beds overturned, strike N 59° E, dip 79° NW. Traverse S 70° E. Beds exposed in bank opposite 185 to 195 feet of traverse are black, soft, argillaceous; at 205 to 215 feet traverse the shale is dark gray to black, distinctly more silty, and scours the hammer. The shale is concealed in the lower part of this interval, but the surface is littered with fragments of black shale, so that only a few feet can possibly belong in the Onondaga formation		45+
ONONDAGA SHALE AND LIMESTONE:		
Thin- to medium-bedded argillaceous limestone, grading to calcareous shale, much concealed. The exposed beds are blocky, bluish-gray when fresh, but weather greenish, and finally yellowish and more		

	Thickness Feet	
	Bed	Total
or less punky. They are somewhat slumped, so that calculations of thickness are based on strikes and dips of the Marcellus and Oriskany. Traverse S 52° E 20 feet, drop 12 feet; S 70° E 77 feet, total 145 feet, to a point about S 10° W 15 feet from highest exposures of Onondaga beds in the old railroad bank. Fossils were collected near the top of the bank, about in place though not strictly so, as follows: 100 feet (opposite 135 feet traverse): *Odontocephalus aegeria* (c)[2], *Kloedenia fililimbata* (rr), *Amphissites (?) altireticulatus* (c), *A. (?) altireticulella* (c), *Ranapeltis divergens* (r), *Favulella dicarinella* (c), *Thlipsurella (?) curvicristata* (r-c), *Beecherella bloomfieldensis* (c-a), *Styliolina fissurella* (aa), brachiopods. At 80 feet (opposite 105 feet traverse): *cf. Phacops cristata* (c), *Bollia platyloba* (r), *B. planojugosa* (r), *Kloedenia fililimbata* (rr), *Amphissites (?) altireticulatus* (c), *A. (?) altireticulella* (c), *Ranapeltis divergens* (c), *Thlipsura thyridioides* (r), *Favulella dicarinella* (r), brachiopods (c). At 65 feet (opposite 80 feet traverse): *cf. Phacops cristata* (c), *cf. Acidaspis callicera* (r-c), *Bollia platyloba* (a), *B. planojugosa* (c), *B. diceratina* (c), *Ulrichia pluripuncta* (rr), *Ranapeltis divergens* (c), *Stibus kothornostibus* and var. *paucipunctus* (r), *Favulella favulosa* (c), *F. dicarinella* (rr), *Styliolina fissurella* (a), brachiopods (c). The Ostracoda at 65 feet represent a characteristic development of the *Bollia platyloba–B. planojugosa* faunule; this appears in a somewhat modified form at 80 feet; the faunule at 100 feet is characterized by *Beecherella bloomfieldensis*, together with *Thlipsurella curvicristata* and the most abundant occurrence of *Favulella dicarinella*.....	55	102
Concealed; traverse S 16° E 38 feet to top of quarry dump, S 52° E 10 feet, total 48 feet, drop 11 feet, to point along strike of base of lowest limestones exposed in bank in 1940. Before the dump was placed here, and before the Onondaga-Oriskany contact had been exposed in the quarry, thin- to medium-bedded argillaceous limestone or calcareous shale, weathering greenish and punky, was exposed about 25 to 30 feet above the base of the Onondaga. If the name "Selinsgrove limestone" is to be used, it may well be desirable to include therein the beds at 25 to 30 feet; but other sections will have to be studied in the area before the lithology will be fully understood. The following Ostracoda were collected in place in these beds by Swartz in 1938; loose material containing the same faunule was obtained by Willard in 1931: *Bollia ungula* (aa), *B. platyloba* (rr), *Amphissites* (?) *altireticulatus* (c), *Thlipsura thyridioides* (c), *Octonaria alticostata* (c), *Ranapeltis dicarinata* (c), *Stibus kothornostibus* and var. *paucipunctus* (c), *S. seriopunctus* (r), *Eustephanus catastephanes* (c), *Favulella favulosa* (a), *F. dicarinella* (rr). This assemblage represents the typical *Bollia ungula* faunule and zone.....	45	47
Thin- to medium-bedded calcareous shale to some very argillaceous limestone, weathering greenish and soft, or in places limonitic and harder, the latter material probably representing the iron ore zone which has been reported at the Onondaga-Oriskany contact in the		

[2] In section descriptions and Table 1 abundance of species is indicated as follows: (aa) very abundant, (a) abundant, (c) common, (r) rare, (rr) very rare.

	Thickness in Feet	
	Bed	Total
New Bloomfield region (Claypole, 1885). There are occasional thin lenses bearing numerous small brownish clayey pelletlike bodies about 1 mm. in diameter; these should be studied to see whether they represent iron carbonate structures. At contact with the Oriskany is several inches of fine gravel embedded in a clayey matrix; this material evidently represents reworking of weathered material from the upper surface of the Oriskany, at the beginning of Onondaga sedimentation. Occasional sand grains are found scattered through this 2 feet of shale	2	2
Disconformity		
ORISKANY SANDSTONE AND CHERT:		
Thick-bedded, somewhat calcareous, finely conglomeratic very coarse-grained sandstone, below; passing at top into rather fine-grained quartz conglomerate; all weathering friable. The grains in the lower to middle parts are commonly 1/16 to 1/8 inch in diameter; in the upper 2 feet, especially, they become 1/8 to 1/4 inch in diameter, with numerous pebbles about 3/8 and a few up to 3/4 inch. No pebbles other than quartz (or, improbably, white quartzite) were observed. The pebbles and sand grains are in general moderately well rounded. Large *Meristella* sp. is abundant about one-third above base of the unit. This is the quarry bed and is the eastward extension of the Ridgeley sandstone. Strike N 60° E, dip 82° NW.	22	37
Thick- to medium-bedded chert, in layers up to a foot thick; mostly weathered white, solid; beds at base, however, weather more limonitic, and are seen as small lumpy pieces in part of the footwall. These latter may represent the uppermost part of the underlying Mandata beds of the Helderberg group of this area. As seen under binoculars, some of the upper beds contain a fair number of small quartz sand grains. Fossils abundant; at middle: *Anoplotheca flabellites* (a), *cf. Spirifer murchisoni* (c), *Diaphorastoma* sp. (c). At base: *Eatonia medialis* (c), *Spirifer* sp. suggestive of *S. concinnus* but large (r), *Anoplotheca flabellites* (r), *A. dichotoma (?)* (c). The white-weathering cherts at least are Oriskany in age	15	15
Concealed.		

Kindle in 1912 described a number of Onondaga exposures in the general neighborhood of New Bloomfield, including a section at Pulpit Rocks, one-eighth of a mile southeast of the town and corresponding closely to the locality above described; a section at Clouser's dam just southwest of the town; one at Falling Springs, 5 miles to the south-southwest; and one at Alinda, 8 miles to the southwest. Kindle recorded a large fauna and regarded its Onondaga age as being proven especially by the trilobites, which include *Phacops cristata, P. cristata* var. *pipa, cf. Greenops boothi* var. *calliteles, Odontocephalus aegeria, O. selenurus, Phaethonides gemmaeus,* and *Acidaspis callicera.*

CLARKS MILL

Highly fossiliferous slabs were obtained about 5 to 10 feet above the base of the Onondaga along the highway to Markelville, Pennsylvania, 1.9 miles by map northwest of the New Bloomfield square, about 200 feet north of the old Clarks Mill building, and about a quarter of a mile north of McKee crossroads. North of a fine section of Keyser limestone are poor exposures of Helderberg and Oriskany cherts and sandstone; the lower part of the Onondaga is then seen in a much weathered condition, and Oriskany sandstone again appears on the northern side of a small syncline.

The following ostracodes have been identified from this material: *Aparchites (?) lenticularis* (c), *Aechmina crassicornis* (c) *A. (?) fimbriata* (rr), *Bollia diceratina* (a), *B. diceratina* var. *fimbriata* (r), *Ulrichia pluripuncta* (c), *Ctenoloculina punctocarinata* (r), *Parabolbina parvinoda* (r), *Amphissites (?) altireticulatus* (c), *Kirkbyella rhomboidalis* (r), *Octonaria multipunctata* (rr), *O. alticostata* (r), *Ranapeltis trilateralis* (c), *Stibus kothornostibus* and var. *paucipunctus* (a), *S. unisulcatus* (c), *Favulella favulosa* (a), *Tubulibairdia paucitubulis* (r), *T. multitubulis* (rr), *Bythocypris (?) perarcuata* (rr), *Cavellina planoloculata* (r).

This faunule is characterized by *Ranapeltis trilateralis,* which is not now known at higher levels in the Onondaga beds, and by the absence of *Bollia ungula, B. platyloba, B. planojugosa,* and of various other species which occur in overlying parts of the formation near New Bloomfield.

SWATARA GAP

The presence of Onondaga limestone along Swatara Creek at the gap cutting through Blue Mountain, in the northeastern part of the Hummelstown quadrangle, Pennsylvania, was recorded by Kindle in 1912 from the occurrence beneath the Marcellus of "loose pieces of black thin-bedded and very impure limestone," containing *Anoplotheca acutiplicata* and *Chonetes mucronatus.* The sequence from Silurian into Devonian rocks, seen along the dirt road on the east side of the creek, was described as follows by C. K. and F. M. Swartz (1931, p. 635):

	Thickness Feet
MARCELLUS FORMATION:	
Black carbonaceous shale. *Liorhynchus limitare* (aa).	
ONONDAGA LIMESTONE:	
Concealed above; impure somewhat argillaceous limestone, below, containing *Phacops cristata, Atrypa reticularis, Leptaena rhomboidalis, Pentagonia unisulcata, Stropheodonta inequistriata*	20

	Thickness Feet
INWOOD SANDSTONE:	
Greenish-gray, argillaceous, somewhat arkosic sandstone, concealed above. Age unknown, probably Cayugan	49
BLOOMSBURG RED BEDS:	
Red sandstone and shale.	

The following Ostracoda were found by Swain in weathered crusts from the Onondaga limestone of the above section: *cf. Ctenoloculina punctocarinata* (rr), *cf. Amphissites (?) altireticulatus* (rr), *Thlipsura* sp. (rr), *Ranapeltis divergens (?)* (r), *cf. Cavellina planoloculata* (r). Preservation is unfortunately rather poor, but the fauna is of interest because of its occurrence at this easterly locality.

MOUNT ROCK, LEWISTOWN

Onondaga beds are exposed in part along the highway on the west side of Kishacoquillas Creek, opposite Mount Rock village, Pennsylvania, at the northern outskirts of Lewistown in the Lewistown quadrangle. The following section is provided by Swain, and is the place where the *Bollia platyloba—B. planojugosa* zone was first discovered:

	Thickness Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale. Green somewhat sandy Hamilton shale is partly exposed 20 to 375 feet higher in the sequence	50	50+
ONONDAGA SHALE AND LIMESTONE:		
Concealed, with some black shale fragments near top. Part of this interval must belong with the overlying Marcellus formation	60	140—
Gray calcareous shale and argillaceous limestone, weathering greenish to buff; seen 110 to 125 feet south of exposed Ridgeley sandstone. Weathered slabs bear molds of numerous fossils, including *Phacops cristata* (c), *P. cristata* var. *pipa* (c), *Greenops boothi* or var. *calliteles* (c), *Acidaspis callicera* (r), *Otarion stephanophora* (r), *Aparchites lenticularis* (c), *Aechmina crassicornis* (c), *Bollia platyloba* (a), *B. diceratina* (a), *B. planojugosa* (c), *B. spinomuralis* (r), *Ulrichia elongata* (c), *Ctenobolbina (?) ventricosa* (r), *Parabolbina parvinoda* (r), *Kirkbyella rhomboidalis* (r), *Thlipsura thyridioides* (c), *Ranapeltis divergens* (r), *Stibus kothornostibus* and var. *paucipunctus* (a), *S. unisulcatus* (r-c), *Cavellina planoloculata* (c), *Favulella favulosa* (a), *Bactrites aciculum* (c), and brachiopods. This is the *Bollia platyloba—B. planojugosa* zone	10	80
Concealed. May include some Ridgeley sandstone at base	70	70
ORISKANY GROUP: RIDGELEY SANDSTONE:		
Thick-bedded, coarse-grained calcareous sandstone, bearing numerous molds of fossils of the *Spirifer arenosus* fauna.		

NORTHEAST OF McVEYTOWN

Parts of the Onondaga shale and limestone are exposed in and near the Mifflin sand quarry, near the southern edge of the area of the Lewistown quadrangle, just west of the highway to Lewistown, about 3 miles northeast of McVeytown, Pennsylvania. The following description is contributed by Swain:

	Thickness Feet
ONONDAGA SHALE AND LIMESTONE:	
Concealed to northwest.	
Thin-bedded calcareous shale, weathering greenish, seen along road leading from the Lewistown highway past the sand quarry. The lower 34 feet is also seen in the face of the quarry, where the lower 6 feet is weathered reddish, and contain throughout numerous flattened pelletlike structures about 1 mm. in diameter, similar to those seen in the basal Onondaga at New Bloomfield. The following fossils were found in the road section, about 1 foot above the base of the Onondaga: *Aparchites* (?) *lenticularis* (r), *Octonaria alticostata* (r), *Stibus kothornostibus* (r), *Chonetes* sp., *Anoplotheca acutiplicata*. This fauna presumably represents the *Ranapeltis trilateralis* zone but needs further study	65
ORISKANY GROUP: RIDGELEY SANDSTONE:	
Medium-grained argillaceous sandstone, weathered friable and with mottled reddish areas as seen in quarry. Age uncertain	6
Medium- to coarse-grained sandstone weathered friable, yellowish. This is the quarry rock and is typical Ridgeley sandstone.	

NEWTON HAMILTON

Onondaga beds were studied at two places near Newton Hamilton, Pennsylvania, a town near the southern border of Mifflin County, in the area of the Mount Union quadrangle. The first and more important of these exposures is seen in a cut along the main line of the Pennsylvania Railroad, about 1¼ miles northeast of the town. The second is found along the road leading to the Lewistown-Mount Union highway, about 1 mile northwest of Newton Hamilton.

The first section provides probably the most complete exposure of the Onondaga to be seen in the region. The beds are not greatly weathered and approximate to an exceptional degree their fresh lithology. The Onondaga-Oriskany contact is well exhibited.

The exposures in the cut have been studied by Willard, and evidently form the main basis for his "composite Onondaga section of Newton Hamilton" (Willard, 1936; 1939, p. 153), which is summarized below. Thicknesses have been totaled by the writers.

	Thickness Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale; exposed	39	39
ONONDAGA GROUP: SELINSGROVE LIMESTONE:		
(g) Limestone, sandy, gray	4	209
(f) Limestone, gray, massive, black shale partings	1–2	205
(e) Shale, dominantly, black and fissile, with large calcareous concretions	19	203
(d) Similar to (e), but fewer iron-stained concretions. This is "Beaver Dam black shale," its limits "vaguely defined in (e) and (c)"	78	184
(c) Similar to (d), but concretions again plentiful	22	106
(b) Similar to (c), concretions rare, but large, up to 5 feet; some are septarian; more abundant below	67	84
(a) Black shale and gray interbeds of platy limestone, the limestone dominant in lower 10 feet. At base a thin sandy limestone rests on uneven top of Oriskany (p. 150)	17	17
Disconformity		
ORISKANY SANDSTONE: exposed	5	5

Study of this section by the writers has yielded a conception of lithologic characters, succession, and thickness which differs radically from Willard's account. The following description is based principally on work by Swartz, modifying and expanding the results of an earlier examination by Swain. Measurements were made with a 6-foot ruler.

	Thickness Feet	
	Bed	Total
ONONDAGA SHALE AND LIMESTONE:		
Concealed above top of cut and to south. Marcellus black shale can be seen along road south of underpass, about ¼ mile south of cut.		
Medium-bedded impure argillaceous limestone in beds frequently 12 to 14 or 15 inches thick weathering gray as seen along cut; and interbedded dark-gray to blackish thin-bedded calcareous shale. The beds of impure limestone predominate in the upper 35 to 40 feet of this interval. The lower beds are seen in a more weathered condition at the top of the southeast wall at about the middle of the cut, and the shales especially have weathered greenish	50	114
Thin-bedded calcareous shale, dark gray to black when fresh, tending to weather gray in cut, and becoming greenish where exposed longer at top of bluff. At 3 and 13 feet above base are more blocky, calcareous layers, 2 to 3 inches thick. This is presumably the main part of Willard's "Beaver Dam black shale," though as found in more weathered exposures, including the crops at the top of the cut, it would doubtless be regarded as normal "Needmore shale"	18	64
Bed of gray argillaceous limestone, prominent in walls of cut, where it is weathered light gray and tends eventually to break into small fragments	1	46

	Thickness Feet	
	Bed	Total
Thin-bedded to nearly fissile dark-gray to black shale, weathering gray to greenish gray in parts of cut. A 1-inch discontinuous bed of impure limestone occurs 2 feet below top	20	45
Interbedded very argillaceous limestone, tending to project on walls of cut in layers 3 to 9 inches thick; and much interbedded dark-gray thin-bedded shale, all weathering gray to somewhat greenish gray where longer exposed. Even the more limy beds tend to break eventually into irregular fragments. The limy beds are not wholly continuous, and individual layers pinch out or pass into shale at several places. At one place on the northwest wall is a limestone lens (not a concretion) about 4 inches thick and 5 feet long. Top of the most prominent limestone layer is 4 feet above base of the unit	5	25
Thin-bedded almost fissile dark-gray to blackish shale weathering greenish where longer exposed near north end of cut. There are scattered nodules of pyritiferous siliceous limestone or impure chert, 1 to 2 inches thick and commonly 5 to 6 inches long; these are generally rare but become fairly common at some places along the cut. About 15 to 16 feet above base is a more or less continuous zone or sometimes zones of these pyritiferous nodules commonly 1 to 3 or 4 inches thick, and weathering rusty. About a foot higher, but at times in contact with the nodules, at times separated from them by up to 3 feet of shale, is a 2- to 3-inch bed of impure limestone, occasionally lenticular, and weathering gray as seen in the cut	18–20	20
Thin-bedded friable black argillaceous sandstone, somewhat variable in thickness, containing occasional *Diaphorastoma* sp. and some other fossils. As seen under the binocular, the sand is somewhat irregularly mixed with black shaly material. According to a test run by O. F. Tuttle, the black material is high in organic material and iron and contains little if any manganese. This argillaceous sandstone apparently represents initial reworking of the weathered summit of the Oriskany at the beginning of Onondaga sedimentation and following a period of emergence. The contact with the underlying calcareous Oriskany sandstone is sharply defined, and in the writers' opinion the blackish layer can not be regarded as due to weathering and discoloration in place of the Oriskany surface	½	½

Disconformity

ORISKANY GROUP: RIDGELEY SANDSTONE:

Thick-bedded solid dark-gray calcareous sandstone, showing sections of shells of large brachiopods of the *Spirifer arenosus* fauna. Where more protected in the cut, the limy content and relatively fresh shells continue virtually to the sharp contact with the overlying black argillaceous sandstone layer, showing that at this place no deeply weathered zone was developed or at least remained in place in the Ridgeley at the time of the post-Oriskany emergence. The top of the Ridgeley rises to track level near milepost 186-167, and then is exposed for several hundred feet to the north. Thickness exposed about	15	
Concealed.		

If the term "Selinsgrove limestone" is accepted as a name for the limestones of the upper part of the Onondaga of the region, it should apply to the 50 feet of limestone and interbedded shale seen at the top of this section, together with any beds intervening between them and the contact with the Marcellus black shale. Although it is obscured by his description, Willard (1939, Fig. 36, "Mifflin County" section) apparently wished to restrict the Selinsgrove near Newton Hamilton to the 5 to 6 feet of limestone (his f and g) which he has presumably seen in contact with the Marcellus at some unspecified place in the vicinity. The relation of these beds to the rocks exposed in the cut is not clear; Willard reports a total thickness of 210 feet of Onondaga in his "composite section" as compared to about 115 feet seen in the cut by the writers.

The shales 46 to 64, together perhaps with the beds 25 to 46 feet above the base of the Onondaga appear to be the "Beaver Dam black shale" of Willard (*Cf.* 1939, Fig. 35 A), despite the differences in description and reported thickness. As can be seen at the top of the embankments, these shales weather gray to greenish and where more commonly exposed in weathered outcrops would exhibit the characters normal to the Onondaga beds of the region. These and other shales in the cut generally effervesce freely when tested with acid; the calcareous content is presumably an important factor in their manner of weathering. Because of their tendency to break into small irregular fragments and their ease of weathering with change to greenish colors, these beds differ in marked degree from the Marcellus shales which are fissile and tend to remain black and relatively firm, although they may gradually lose color after extended exposure. In the writers' opinion the characters of these shales do not warrant their separation as a distinct member of the formation. In any event, the comment that they are "very like the Marcellus" does not properly portray their lithologic characters.

The "large calcareous concretions" to which Willard refers are presumably the bedded limestones which are prominent at several levels in the walls of the cut. In general, these layers do not show unusual variations in thickness as they are traced with gentle dip along the embankments. Rarely, as in some of the layers 20 to 25 feet above the base of the Onondaga, there is a tendency to form elongate lenses; but in the writers' opinion even these are not concretions.

Brachiopods and mollusks can be collected in the cut and are worthy of further study; but this material is too fresh to supply satisfactory ostracode molds. Some promising slabs were collected at the top of the southeast wall but have not yet been worked up.

The section along the road to the Lewistown-Mount Union highway, about 1 mile northwest of Newton Hamilton, affords a fairly good limiting value for the thickness of the Onondaga in this vicinity, provides material from which ostracodes have been obtained, and exhibits the weathering characteristics of part of the Onondaga beds seen in the railroad cut. The section was studied by Swartz.

	Thickness Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale, exposed along highway for about 350 feet traverse. Greenish-gray shale of Hamilton type is then seen to the southeast	105	105
ONONDAGA SHALE AND LIMESTONE:		
Concealed, with black shale of Marcellus type littering the bank near top. Traverse N 67° E 120 feet, rise 4°. May include a small thickness of Marcellus shale in upper part	35	125±
Thin-bedded calcareous shale and some interbedded impure limestone, all weathering greenish. There is little of the limestone in the lower half, but it becomes abundant near the top. Traverse N 67° E 135 feet, rise 4½°. Strike N 30° E, dip 24° SE. Fossils were obtained as follows, 75± feet (25 feet above base of exposed beds): *Bollia planojugosa* (c), cf. *Ctenoloculina punctocarinata* (rr) *Amphissites (?) altireticulatus* (c), *A. (?) altireticulella* (c), *Thlipsura thyridioides* (c), *Stibus kothornostibus* and var. *paucipunctus* (c), *S. unisulcatus* (c), *S. seriopunctus* (r), *Euglyphella* sp. (rr). At 70± feet: *Bollia diceratina* (c), *B. planojugosa* (c), *Ranapeltis divergens* (c), *Stibus kothornostibus* and var. *paucipunctus* (c), *S. unisulcatus* (c), *Favulella favulosa* (c), cf. *Odontocephalus aegeria* (r), brachiopods. At 60± feet: *Bollia diceratina* (r), *B. planojugosa* (r). These faunules contain *Bollia planojugosa* and apparently represent a late expression of the *Bollia platyloba-B. planojugosa zone*	40	90±
Concealed. Traverse S 58° E 110 feet, rise about 6°, beginning about at top of Ridgeley sandstone on northeast side of highway	50±	50±
(Disconformity)		
ORISKANY GROUP: RIDGELEY SANDSTONE:		
Thick-bedded sandstone, forming a knoll littered with sandstone boulders.		

Judging from the topography near the Oriskany contact, the lower concealed part of the Onondaga of this section might be as much as 60 feet thick, making a total of not more than 135 feet for the Onondaga near Newton Hamilton. The manner in which the limestone beds occur suggests that not more than the upper half of the Onondaga beds exposed in this section belongs in the upper 50 feet of limestone and interbedded shale seen in the near-by railroad cut. If this is true, then about the lower half of the Onondaga beds exposed here represents the weathered

phase of the "Beaver Dam" dark-gray to black shales occurring below the upper limestones of the railroad section.

JACKSON CORNER

Onondaga shale and limestone beds are partially exposed along and near the highway to McAlevys Fort, about 12 miles northeast of Huntingdon, Pennsylvania, just southwest of Jackson Corner in the Allensville quadrangle. Some ostracodes were found in the lower shales but have not been studied. Bearings are magnetic. The section was measured by Swartz.

	Thickness in Feet	
	Bed	Total
ONONDAGA SHALE AND LIMESTONE:		
Concealed for about ¼ mile to the south; Marcellus black shale is then exposed along the roadside.		
Medium-bedded mostly very argillaceous limestone, in layers 3 to 12 or 14 inches thick; and much interbedded dark-gray to sooty black thin-bedded to more or less fissile calcareous shale; the shale beds tend to weather gray to greenish gray. A few of the limestones are moderately pure and break with conchoidal fracture; one bed weathers with worm-tubelike openings and its fragments are conspicuous in the talus. Some of the impure limestones in the upper part of this sequence are coquinites and contain a profusion of shells of small brachiopods varying in different beds, and including *Ambocoelia* sp., *Meristella (?)* sp., and *Strophalosia truncata*, the latter common but not profuse. *Orbiculoidea lodiensis* var. *media* is rare to common. If the name "Selinsgrove limestone" is to be used, these beds and overlying parts of the Onondaga should be included therein. They are seen in a cut directly alongside the highway about ⅕ mile southwest of the road intersection at Jackson corner	25	80
Thin-bedded, in part more or less fissile dark-gray shale weathering gray to greenish; with a few 3- to 6-inch layers of very argillaceous limestone, and with two 10- to 12-inch such layers near top. The lower of these two thick limestone beds might be regarded as the base of the "Selinsgrove limestone." Seen along entryway to a private garage. Traverse S 4° W 92 feet; strike N 64° E, dip 22° SE.	30	55
Concealed. Traverse S 38° W 170 feet, drop 8 feet	25	25
(Disconformity)		
ORISKANY GROUP: RIDGELEY SANDSTONE:		
Thick-bedded, coarse-grained sandstone, weathering whitish to yellowish, friable; seen along bank of curve of former road cut off by present highway; fossiliferous. It is not wholly certain that this sandstone is in place. The topography would favor a somewhat lower position for the contact. The strike and dip suggest, however, that the beds belong at their observed position	5	
Concealed for some distance to north, then with high ledges of Ridgeley sandstone.		

MARTIN GAP

The thickness of the Onondaga formation is reasonably well shown by a section at Martin Gap, Pennsylvania, in the Allensville quadrangle about 2 miles southeast of Jackson Corner. The ridge through which the gap is cut is composed of Ridgeley sandstone which forms large boulders along Martin Creek and on the slopes on each side of the gap. The following account is provided by Swartz; bearings are magnetic.

	Thickness in Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale exposed for some distance to the northwest. At the base of the exposure is about 1 foot of blocky blackish shale weathered a dark brown. Not measured.		
ONONDAGA SHALE AND LIMESTONE:		
Mostly concealed, with greenish shale fragments in soil at least in lower part, and with some green shale in bank at 161 to 163 feet traverse. Traverse N 12° W 40 feet, total 193 feet	23	135±
Thin-bedded shale weathering greenish; with beds of sparingly fossiliferous argillaceous limestone up to 1 foot or more in thickness at 131, 140, and 147 feet traverse, and a few thinner beds of impure limestone or blocky calcareous shale at higher levels; the limestones weather greenish and tend to break into irregular fragments. These beds would form part of the "Selinsgrove limestone," if that name is to be used. Traverse N 12° W 28 feet, total 152 feet; strike N 32° E, dip 60° NW	17	107±
Concealed; exact position of Oriskany-Onondaga contact somewhat uncertain. Traverse N 23° W 125± feet	90±	90±
(Disconformity)		
ORISKANY GROUP: RIDGELEY SANDSTONE:		
Very thick-bedded, rather coarse-grained, somewhat calcareous sandstone, making ledges on hill, and along and near creek forming boulders often 10 feet or more across. Top of Oriskany reaches road about 25 feet northwest of bridge crossing creek; this position may be a little low stratigraphically, and the thickness referred to the Onondaga may be a little too great. The Oriskany beds were not measured.		

NEAR HOLLIDAYSBURG

The most westerly exposures of Onondaga beds in Pennsylvania are along the crops of inclined strata just east of the Allegheny Front. Kindle in 1912 (p. 32-34) described three sections in this general belt in Pennsylvania, all near Hollidaysburg in the area of the Hollidaysburg quadrangle. Summaries of two of these sections are given below.

(1) Section about 1 mile east of Hollidaysburg square, along highway to Frankstown:

	Thickness Feet
Fissile black clay shale	20+
Greenish buff blocky clay shale (Onondaga)	10
Fine-grained sandstone (Oriskany)	—

(2) Section 1½ miles south of Upper Reese station, about 4 miles east of Hollidaysburg:

	Thickness Feet	
	Bed	Total
Fissile black clay shale (Marcellus)	30+	
Covered	60±	133±
Greenish shale, somewhat calcareous, with 1 foot beds of limestone 3, 22, and 25 feet above base. *Odontocephalus aegeria* and other Onondaga fossils	31	73
Fissile black shale, containing *Chonetes mucronatus* above, *Orbiculoidea lodiensis* var. *media* below	32	42
Covered; light-colored shale soil; 6-inch red iron ore band at base	10	10
Sandstone (Oriskany)	20+	

In view of Kindle's report of fissile black shale in the intervals 10 to 30 and 10 to 42 feet, respectively, above the top of the Oriskany in these two sections, it seemed most desirable to re-examine the Onondaga of the Hollidaysburg area and to determine if possible whether the Onondaga is there interfingering with black shale of Marcellus type. The section south of Upper Reese has unfortunately not been visited. Other sections were, however, examined by Swartz in preliminary fashion both near Hollidaysburg and about 15 miles farther north near Tyrone. The faunas have not yet been studied and the sections are worthy of much additional work.

Kindle's section about 1 mile east of Hollidaysburg has been improved by recent excavations, although the exposures are seen along an abandoned part of the old road to Frankstown and not directly along the new highway constructed in 1938. It is now clear that the black shale seen here is Marcellus as was apparently suspected by Kindle, and that much of the Onondaga is cut out by faulting.

A more instructive section has been exposed in a cut of the new highway just east of Frankstown and about 2½ miles northeast of Hollidaysburg. The following succession is seen at this place. Directions are magnetic.

MARCELLUS BLACK SHALE:

Fissile black shale, exposed in a highway cut. Strike N 0° E, dip 20° to 25° W. Not measured.

ONONDAGA SHALE AND LIMESTONE:

Concealed. Some fragments of green-weathering shale and impure limestone loose in bank in lower part; interval may include some

	Thickness in Feet	
	Bed	Total
Marcellus black shale above. The thickness is uncertain because of reversal of dip from Onondaga below to Marcellus above; there may even be a small fault. Traverse N 58° E 180 feet, total 337 feet.....	30±	80±
Thin-bedded shale, weathered greenish, with a few thin interbeds of impure argillaceous limestone. Traverse N 58° E 110 feet, total 157 feet.....	25	50
Thin-bedded to nearly fissile dark-gray shale, appearing almost black when wet; weathered green near the former surface. At 20 feet: *Orbiculoidea lodiensis* var. *media* (r), *Anoplotheca acutiplicata* (c). The shales contain little carbonate, the freshest shale in the cut not effervescing appreciably with acid. Traverse N 71° E 47 feet, beginning at road level about 5 feet thickness above base of shale.....	22	25
Dark, somewhat bluish-gray chert, with occasional sand grains commonly 0.2 to 0.3 mm., sometimes to 1 mm. in diameter, and with small disseminated grains of pyrite. The chert weathers brownish; the fresher parts scarcely effervesce with acid but should be tested for iron carbonate. The sand grains, and the chert material itself may have been derived by reworking of the summit of the Oriskany sandstone. A further study is needed to show how much of the fine-grained matrix may be clastic rather than nonclastic.....	1½	3
Concealed. The overlying chert is flexed away from the underlying sandstone and overturned by creep, with the enlarged interval filled with a clay soil. The thickness is somewhat uncertain because of the flexure, but is probably about correct and may be composed of shale.	1½	1½

(*Disconformity at this position?*)

ORISKANY GROUP: RIDGELEY SANDSTONE:

Thick-bedded calcareous sandstone exposed in first highway cut east of Frankstown. The upper 1 or 2 feet is less calcareous than are the lower parts, and the uppermost ½- to 1-foot bed especially is hard, quartzitic, at first sight is chertlike in character, and is much jointed; some of the joints are open, especially toward the upper surface and are in places bridged by quartz crystals. Under the binoculars, the sand grains in the uppermost bed are cemented by chert which at some points makes a considerable part of the rock. The surface of this layer bears a few pieces of small gravel, around 2 to 3 mm. in diameter. The characters of this layer, and the paucity of lime may be due to weathering in place during the post-Oriskany emergence. The upper 7½ feet consists of medium-grained sandstone; beds 7½ to 9½ feet below the top are slightly coarser; 9½ to 12 feet below the top the sandstone is very coarse with grains commonly 3 to 4 mm. in diameter. Below this the beds are medium-grained, are rather strongly calcareous, and contain numerous fossils of the *Spirifer arenosus* fauna. The uppermost layers of the Ridgeley of this section deserve further study, both lithologic and faunal, to determine more fully their relation to the post-Oriskany emergence.

In any event, the Oriskany—Onondaga contact at this locality is quite different in character from that seen at Newton Hamilton, where a few inches of reworked argillaceous sand at the base of the shale are in direct and sharp contact with calcareous sandstone containing abundant and unweathered Ridgeley fossils.

TYRONE

One of the finest exposures in Pennsylvania of the sequence from the Onondaga into the overlying Marcellus beds is found along a short dirt road leading southeast from the highway to Altoona, about 2½ miles southwest of Tyrone, Pennsylvania. This locality is about 1 mile south of Grazierville in the area of the Altoona quadrangle, and just ¼ mile south of the overpass where the highway crosses the main line of the Pennsylvania Railroad. The faunas have not been studied. The following description has been provided by Swartz. The traverse crosses the beds in ascending order; bearings are magnetic.

	Thickness Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale. At 138 feet of total traverse is a large septarian gray limestone nodule, about 1¼ feet thick and about 2 feet along bedding. The septarian fissures are lined with moderately coarse crystals, apparently calcite of the "dog-tooth spar" type, enclosing a finer-grained median portion, in part weathered red probably from siderite. The shale layers are depressed stratigraphically below the nodule, and tend to arch above it. There is some minor folding in the shales of the lower part of the interval, but for the most part the dip is about vertical. Traverse N 39° W 140 feet to exposures at side of highway; the contact with the Hamilton shale was not located, and this is not necessarily the full thickness of the Marcellus.....	120	127
Fissile black shale in very thin layers and weathering dark brown in color; at top a 3- to 6-inch bed of very argillaceous or finely silty laminated limestone, weathering dark brown and breakable into thin flat-sided plates. The shale layers are thinner and more fragile than are the overlying black shales typical of the Marcellus of the region; the topmost bed might be regarded as blocky calcareous shale rather than limestone. *Styliolina fissurella* (c). Traverse N 39° W 2 feet total 98 feet.....	2	7
Thin-bedded platy to fissile blackish shale weathering dark brown; and a few thin interbeds of black impure unfossiliferous limestone. *Styliolina fissurella* (c). These and the immediately overlying shales and impure limestones have been included provisionally in the Marcellus because they do not contain so far as observed the brachiopod faunas of the underlying Onondaga beds and are so different from them in lithology. Traverse N 39° W 5 feet, total 96 feet.....	5	5
ONONDAGA SHALE AND LIMESTONE:		
Thin- to medium-bedded more or less argillaceous gray limestone and much interbedded dark-gray to blackish thin-bedded to irregu-		

	Thickness Feet	
	Bed	Total
larly fissile shale, weathering grayish brown to greenish. At base is a 6- to 8-inch somewhat pyritiferous impure argillaceous unfossiliferous dense limestone. Higher limestones are almost all highly fossiliferous coquinites with great numbers of small shells commonly 2 to 3 or 5 mm. in diameter, and imparting a peculiar texture to the beds. Some of the shale layers contain similar but generally broken and less well-preserved shells. The shells differ in different horizons, the following forms having been observed at the traverse positions indicated. 89 feet: *Meristella* sp., small (profuse). 87 feet: gently convex subcircular shell, hinge denticulate, diameter 3 to 4 mm., may be nearly symmetrical pelecypod (profuse); *Meristella* sp. as above (c). 76 feet: *Ambocoelia* sp., 2 to 3 mm. in diameter (profuse). Traverse N 39° W 25 feet, total 91 feet. Strike N 57° E, dip 87° NW. These beds could be classed as "Selinsgrove limestone"	24	82
Thin-bedded calcareous shale weathering greenish, and some thin interbeds of impure argillaceous limestone. Traverse N 73° W 35 feet, N 45° W 13 feet, total 73 feet. Dip 67° NW	37	58
Thin-bedded shale weathering greenish; poorly exposed. Traverse N 73° W 25 feet	18	21
Thin-bedded impure chert weathering limonitic and in part hematitic; poorly exposed in bank at entrance to small pit at end of the road	3±	3±

(*Disconformity?*)

ORISKANY GROUP; RIDGELEY SANDSTONE:

Coarse-grained sand weathered loose and limonitic, and seen in pit which may have been an iron ore prospect; this sand appears to be in place just below the chert beds. Surface to southeast and east bears numerous boulders of coarse-grained Ridgeley sandstone containing molds of Oriskany fossils.		

Study of the above described section together with the sequence seen at Frankstown shows that although some of the shales of the Onondaga of this area are dark gray or even black when fresh, none take on the characters of the black shales of the Marcellus, and no satisfactory evidence has been found of appreciable interfingering of the Onondaga with beds of Marcellus facies. Part of the upper limestones and shales are exposed in a cut along the cement highway about ¼ mile south of this section. The beds are overturned, with the Onondaga-Marcellus contact concealed beneath the highway. The exposed Onondaga shales are all weathered greenish.

The chert at the base of the Onondaga at this locality appears to be a continuation of the chert at the same stratigraphic position at Frankstown.

LOCK HAVEN

Some thin limestones, possibly Onondaga in age, are seen at the base of the Marcellus black shale along a dirt road just west of the highway from Howard to Lock Haven, Pennsylvania, at the east edge of the Howard quadrangle. The dirt road branches west from the highway a short distance north of the highway fork which leads to Mill Hall, and is about ½ mile north of Brown School.

Contact with the underlying Oriskany beds is not exposed. The limestones, which are dark gray to black, dense, argillaceous, contain *Strophalosia truncata* and *cf. Bollia diceratina* and suggest some of the limestones of the upper part of the Onondaga at Jackson Corner and Tyrone. Further work is needed to establish their age and relationships.

WARREN POINT

Onondaga beds are partially exposed along the highway to Millstone, Maryland, about 1¼ miles southwest of Yeakle Mill, Pennsylvania, and just east of the bridge crossing Licking Creek, in the northeastern part of the Hancock quadrangle. The section is about 1 mile southeast of Warren Point, Pennsylvania, at the southern end of Keefer Mountain, and has long been known as the Warren Point section (Rowe, 1900; Swartz, 1912; Prosser, 1913, p. 83). The following measurements were obtained by Swain:

	Thickness in Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Black fissile shale.		
ONONDAGA SHALE AND LIMESTONE:		
Greenish-gray calcareous shale, with thin layers of dense dark-gray argillaceous limestone about 1 to 6 inches thick. No fossils observed.	45	115
Concealed	5	70
Thin-bedded gray shale weathering greenish and containing *Bollia platyloba* (c), *Ctenoloculina punctocarinata* (r), *Parabolbina parvinoda* (r), *Ctenobolbina* (?) *ventricosa* (r), *Thlipsura thyridioides* (r), *Octonaria alticostata* (r), *Ranapeltis divergens* (r), *Cavellina planoloculata* (?) (r), *Favulella favulosa* (a), *Greenops boothi* or var. *calliteles, Bactrites aciculum, Anoplia nucleata, Pholidostrophia pennsylvanica.* The faunule represents the *Bollia platyloba—B. planojugosa* zone	5	65
Mostly concealed; near base, some gray to greenish shale. As already shown by the above cited workers, the sharp contact with the Ridgeley and presence in the basal Onondaga of some quartz pebbles probably derived from weathering and reworking of the summit of that sandstone, provide evidence that the contact is disconformable.	60	60
Disconformity		

ORISKANY GROUP: RIDGELEY SANDSTONE:

Thick-bedded calcareous sandstone, blue gray when fresh, containing the *Spirifer arenosus* fauna of the Oriskany; at top, a 6- to 8-inch conglomerate bed largely composed of rounded quartz pebbles.

BERKELEY SPRINGS

The Onondaga shale is well exposed in cuts for the entryways leading into the quarry of the Pennsylvania Glass Sand Company, on the east side of Warm Spring Ridge, about 2 miles north of Berkeley Springs, West Virginia, in the area of the Hancock quadrangle. The following section was measured by Swartz in the more northerly of these cuts.

	Thickness Feet	
	Bed	Total
MARCELLUS BLACK SHALE:		
Fissile black shale, not measured.		
ONONDAGA SHALE AND LIMESTONE:		
Thin-bedded gray calcareous shale weathering greenish; poorly exposed	5	110
Concealed	10	105
Thin-bedded gray calcareous shale to impure limestone, weathering punky. 15 to 20 feet above base: *Bollia planojugosa* (c), *B. diceratina* (r), *Ctenoloculina punctocarinata* (r), *Amphissites* (?) *altireticulatus* (a), *Thlispura thyridioides* (r), *cf. Octonaria multipunctata* (r), *Ranapeltis divergens* (r-c), *Stibus unisulcatus* (r), *S. seriopunctus* var. (r), *Favulella favulosa* (c), *Odontocephalus selenurus* (c), brachiopods. This faunule apparently represents a late expression of the *Bollia platyloba—B. planojugosa* zone of the New Bloomfield section	25	95
Fissile black shale, somewhat crumpled	1-1½	70
Thin-bedded gray shale, weathering greenish and tending to break into irregular fragments. There are a few thin impure limestone layers, 1 to 2 inches thick; 2 feet below top is a more prominent 4-inch bed	66	69
Thin-bedded shale, poorly exposed, weathered red and hematitic	3	3
(*Disconformity*)		
ORISKANY GROUP: RIDGELEY SANDSTONE:		
Thick-bedded sandstone, weathering whitish, friable. Contains *Spirifer arenosus, Rensselaeria marylandica,* and many other Oriskany fossils. Not measured. This is the quarry bed.		

COOPER MOUNTAIN

The most southerly locality from which Ostracoda were obtained for this study is a roadside quarry exposing about 30 feet of green-weathering Onondaga shale, and located on the east slope of Cooper Mountain, West Virginia, on the northern side of the highway to Romney about 3 miles west of Cacapon Springs. This point is near the western edge of the

area of the Winchester quadrangle, and is just east of the 78° 30′ longitude line on trip route maps of the Sixteenth International Geological Congress (Butts, 1933, pl. 11) and of the Virginia Geological Survey (Butts, 1938, pl. 3). According to Butts, who donated ostracode-rich slabs found in the upper beds of the quarry, the Onondaga of this area consists of gray to greenish, moderately calcareous shale, about 75 feet thick.

The following species have been identified from the ostracode-bearing slabs: *Bollia platyloba* (c), *B. planojugosa* (r), *B. diceratina* (a), *Kloedenia rectangularis* (rr), *Thlipsura thyridioides* (c), *Stibus kothornostibus* and var. *paucipunctus* (c), *Favulella favulosa* (c), *Phacops cristata* (c), *Octarion* sp. (r), brachiopods. The faunule represents the *Bollia platyloba-B. planojugosa* zone of the New Bloomfield section.

STRATIGRAPHIC SIGNIFICANCE OF THE ONONDAGA OSTRACODES

LIST OF DESCRIBED SPECIES AND USE FOR ZONAL WORK IN MIDDLE APPALACHIAN REGION

The ostracodes obtained during the present study are listed in Table 1, with notations on their occurrence and relative abundance at each of the localities where material was obtained. Examination of this table of distribution, together with the section descriptions, will bring out several important relationships. First, the Onondaga beds of the region contain an abundant and varied assemblage of ostracodes; second, a considerable number of the species have already been found at rather widely separated localities; third, the New Bloomfield and near-by Clarks Mill exposures reveal at least four reasonably distinct ostracode zones. In addition, only one of the species is now known in the middle Appalachian region from a horizon other than the Onondaga beds.

The ostracodes of the Onondaga beds of the area studied are not only varied and abundant, as is indicated by the faunal list, but also, as can be seen by the illustrations, include many forms with types of complex and distinctive ornament favorable to critical identification. A good many of the species have already proved to have extensive geographic ranges. Belonging in this category are such forms as *Bollia diceratina, B. planojugosa, B. platyloba, Thlipsura thyridioides, Octonaria alticostata, Ranapeltis divergens, Stibus kothornostibus,* and *Favulella favulosa.* Save in the uppermost beds, the fauna as a whole is especially characterized by *Bollia diceratina* and *Favulella favulosa,* and can well be named after these two species. *Thlipsura thyridioides* and *Ranapeltis divergens* are also very significant species.

A fairly complete sequence of ostracode faunules has been obtained in the sections at New Bloomfield and near-by Clarks Mill. Four reason-

TABLE 1. *Distribution of studied species*

TABLE 1. *Distribution of studied species*

	New Bloomfield				Clarks Mill	Mount Rock	Newton Hamilton			Warren Point	Swatara Gap	Cooper Mt.	Berkeley Springs
	100	80	65	25	5–10	70–80	75	70	60	60–65			85–90
Aparchites (?) lenticularis Swartz and Swain, n. sp.					(c)	(c)							
Aechmina crassicornis Swartz and Swain, n. sp.					(c)	(c)							
A. (?) fimbriata Swartz and Swain, n. sp.					(rr)								
Bollia ungula Jones				(aa)									
B. platyloba Swartz and Swain, n. sp.		(r)	(a)	(rr)		(a)				(c)		(r-c)	
B. hindei Jones (Hamilton shale, Ontario)													
B. obesa Ulrich (Jeffersonville limestone, Kentucky)													
B. diceratina Swartz and Swain, n. sp.			(c)		(a)	(a)		(c)	(r)			(a)	(r)
B. diceratina var. *fimbriata* Swartz and Swain, n. var.					(r)								
B. planojugosa Swartz and Swain, n. sp.		(r)	(c)			(c)	(c)	(c)	(r)			(r)	(c)
B. spinomuralis Swartz and Swain, n. sp.						(r)							
Ulrichia pluripuncta Swartz			(rr)		(c)								
U. elongata Swartz and Swain, n. sp.						(c)							
Parabolbina parvinoda Swartz and Swain, n. sp.					(r)	(r)				(r)			
Ctenobolbina (?) ventricosa Swartz and Swain, n. sp.						(r)				(r)			
Ctenoloculina punctocarinata Swartz and Swain, n. sp.					(r)		(?r)			(r)	(r)		(r)
Kloedenia rectangularis Swartz and Swain, n. sp.												(rr)	
K. fildimbata Swartz and Swain, n. sp.	(rr)	(rr)											
Amphissites (?) altireticulatus Swartz and Swain, n. sp.	(c)	(c)		(c)	(c)		(c)				(rr)		(a)
A. (?) altiretsculella Swartz and Swain, n. sp.	(c)	(c)					(c)						
Kirkbyella rhomboidalis Swartz and Swain, n. sp.					(r)	(r)							
Thlipsura thyridioides Swartz and Swain, n. sp.		(r)		(c)		(c)	(c)			(r)		(c)	(r)
T. sp.											(rr)		
Octonaria stigmata Ulrich (Jeffersonville limestone, Kentucky)													
O. loculosa Ulrich (Jeffersonville limestone, Kentucky)													
O. multipunctata Swartz and Swain, n. sp.					(rr)								
O. alticostata Swartz and Swain, n. sp.				(c)	(r)					(r)			
Thlipsurella curvicristata Swartz and Swain, n. sp.	(r-c)												
Eustephanus catastephanes Swartz and Swain, n. g., n. sp.				(c)									
Stibus kothornostibus Swartz and Swain, n. g., n. sp.			(r)	(c)	(a)	(a)	(c)	(c)				(c)	
S. kothornostibus var. *paucipunctus* Swartz and Swain, n. var.			(r)	(c)	(c)	(c)	(c)	(c)				(r)	
S. uniculcatus Swartz and Swain, n. sp.					(c)	(r)	(c)	(c)					(r)
S. seriopunctus Swartz and Swain, n. sp.				(r)			(r)						(var. r)
Favulella favulosa (Jones), Swartz and Swain, n. g.			(c)	(a)	(a)	(a)		(c)		(a)		(c)	(c)
F. dicarinella Swartz and Swain, n. sp.	(c)	(r)	(rr)	(rr)									
Ranapeltis dicarinata Swartz and Swain, n. g., n. sp				(c)									
R. trilateralis Swartz and Swain, n. sp.					(c)								
R. divergens Swartz and Swain, n. sp.	(r)	(c)	(c)			(r)		(c)		(r)	(?r)		(r-c)
Euglyphella sp.							(rr)						
Beecherella bloomfieldensis Swartz and Swain, n. sp.	(c-a)	(c)											
Tubulibairdia paucitubulis Swartz and Swain, n. sp.					(r)								
T. multitubulis Swartz and Swain, n. sp.					(rr)								
Bythocypris (?) perarcuata Swartz and Swain, n. sp.					(r)								
Cavellina planoloculata Swartz and Swain, n. sp.					(r)	(c)				(?r)	(?r)		

* In this table as in the section descriptions, (aa) stands for very abundant, (a) for abundant, (c) for common, (r) for rare, (rr) for very rare.

ably distinct zones are revealed at these localities. In descending order, these are:

Bollia diceratina Favulella favulosa fauna

- Zone of *Beecherella bloomfieldensis*, together with *Thlipsurella curvicristata* and main occurrence of *Favulella dicarinella; Bollia planojugosa* and *B. platyloba* rare or absent, as are *B. diceratina* and *Favulella favulosa.*
- Zone of *Bollia platyloba* and *B. planojugosa; B. platyloba* becomes less abundant above; *Ranapeltis divergens* occurs chiefly in this zone.
- Zone of *Bollia ungula*, together with *Ranapeltis dicarinata.*
- Zone of *Ranapeltis trilateralis*, without *Bollia ungula, B. platyloba*, and *B. planojugosa.*

The faunules obtained at most of the other sections represent the *Bollia platyloba- B. planojugosa* zone of the New Bloomfield area. Frequently, however, *B. platyloba* is rare or at least was not observed, suggesting the higher part of the zone. It may prove desirable to split the zone in two on this basis.

It should be emphasized that the present paper by no means completes the study of the ostracodes of the Onondaga beds of the middle Appalachian region. It will be especially desirable to search at other localities for the complete suite of zones recognized at New Bloomfield, and to further check the species ranges as now understood.

BEARING ON RELATIONS WITH ENCLOSING BEDS

Ostracodes are virtually unknown in the post-Onondaga beds of the Pennsylvania, Maryland, and Virginia areas, so that the group does not as yet provide direct data concerning relations with the younger beds of this region. Many of the pre-Onondaga formations, on the other hand, contain them in abundance. The youngest such is the Shriver siliceous limestone or impure chert, currently regarded as early Oriskany in age. The Shriver is separated from the Onondaga beds by the Ridgeley sandstone, which is commonly 100 to 200 feet thick, and contains the *Spirifer arenosus* fauna of the typical Oriskany of New York. No ostracodes are known in the Ridgeley.

Only one ostracode—*Ulrichia pluripuncta*—is now known to occur in both the Onondaga and Shriver beds. Other Onondaga species are clearly related to Shriver forms and are later developments of characteristic Shriver stocks. Thus, the Onondaga *Bollia planojugosa* is a derivative of the gens represented in the Shriver by *B. burgeneri* and *B. sagittaformis; Bollia diceratina* is similarly related to the Shriver *B. americana* and *B. zygocornis*, and *Thlipsura thyridioides* to the Shriver *T. confluens. Bollia cristata* of the Shriver is close to and was at one time considered identical with *B. ungula* of the Onondaga.

As compared to the above cited intimate relatives, such Onondaga species as *Favulella favulosa, Stibus kothornostibus* and its variants, *Ranapeltis dicarinata* and its close relatives, *Eustephanus catastephanes,* and *Euglyphella* sp. represent distinctly new generic types, not close to any of their known Shriver forerunners. With the exception of *Ranapeltis,* these genera are also absent from the known Ostracoda of the post-Oriskany Camden chert of western Tennessee (Bassler, 1941), and the Camden furthermore includes important Oriskany elements.

On the whole, these observed differences in the Ostracoda are in accord with the physical evidence of disconformity seen at the Oriskany-Onondaga contact in the middle Appalachian region. Indeed, the hiatus may well be sufficient to account for the absence of the 300 to 500 feet or more of the Esopus shale of southeastern New York and eastern-most Pennsylvania. Furthermore, the evidence of the nonostracode groups must be kept in mind. Among these, the high percentage of reported Marcellus and Hamilton elements in the Onondaga of Pennsylvania and Maryland (Swartz, 1913) seems to favor a somewhat greater value for the disconformity than is now suggested by the ostracodes.

COMPARISONS WITH OSTRACODES FROM ONONDAGA LIMESTONE IN NEW YORK

A number of ostracodes have been described from the typical Onondaga limestone of New York. These are as follows:

Leperditia cayuga Hall (1862)
Primitia clarkei Jones (1890)
Bollia subquadrata (*Beyrichia subquadrata* Jones) (1890)
B. bilobata Jones (1890)
Kloedenia sp. (*Beyrichia kloedeni* McCoy var. Jones) (1890)
Treposella reticulosa (Bassler and Kellett) (= *Eurychilina reticulata* Jones not Ulrich) (Jones 1890; Bassler and Kellett 1934)
Condracypris (*?*) *kirkbyi* (*Moorea kirkbyi* Jones) (1890)

Of the above, the *Kloedenia* suggests *K. rectangularis* of this paper. The specimen figured by Jones is a female valve shown with a peculiarly tuberculose pouch; *K. rectangularis* is established on molds of a male valve from Cooper Mountain, West Virginia, and the characteristics of the female are uncertain. *Bollia subquadrata* and *B. bilobata* are close relatives of *B. ungula* and *B. planojugosa,* respectively. Warthin (1937) regards *B. subquadrata* as being distinct in minor details from *B. ungula;* his new figure (card 38) indicates that the inner ridge of *B. bilobata* is quite different from that of *B. planojugosa.*

Treposella reticulosa and *Condracypris (?) kirkbyi* belong to genera unknown in the Onondaga of Pennsylvania. *Leperditia cayuga* and *Primitia clarkei* are of uncertain relationships; the first was never figured

and was established on a poorly preserved specimen; the second as illustrated by Jones might be the internal mold of an *Amphissites*.

Critical comparisons of the Ostracoda described here with those of the Onondaga limestone of New York must obviously await further studies of collections from the latter beds. The material now known is not indicative of close relationship.

COMPARISONS WITH OSTRACODES FROM JEFFERSONVILLE LIMESTONE IN KENTUCKY

Numerous and varied ostracodes of the Middle Devonian Jeffersonville limestone near Louisville, Kentucky, were made known 50 and 40 years ago by Ulrich (1891, 1900) in two papers which are important milestones in the development of our knowledge of the Paleozoic forms. The Jeffersonville beds have commonly been regarded as a fairly close equivalent of the Onondaga limestone of New York.

Ulrich in 1891 reported the New Bloomfield species, *Bollia ungula*, in the Jeffersonville beds; the following Jeffersonville species were subsequently identified by Kindle in 1912 from the shaly Onondaga of Pennsylvania:

Leperditia (?) subrotundus Ulrich
Bollia obesa Ulrich
Octonaria stigmata Ulrich

The holotypes of *Bollia obesa* and *Octonaria stigmata* were examined in the course of this investigation, and topotypes from the Ulrich and Bassler collections at the United States National Museum are here figured. With present species concepts, their supposed middle Appalachian synonyms are clearly distinct and are here named *Bollia diceratina* and *Octonaria alticostata*, respectively. Jeffersonville specimens of *Paraparchites ("Leperditia") subrotundus* have not been seen. Ulrich's figures, however, show this species with a comparatively long hinge, the length of the valve distinctly greater than the height, the surface of the valve encircled except ventrally by a well-marked flattened border. The supposed counterpart in the Onondaga of Pennsylvania is notably different in these respects, and is here named *Aparchites (?) lenticularis*. Finally, relationship of the Jeffersonville *Bollia ungula* to the New Bloomfield types is not clear, and this question must await further study.

The present investigation has not brought to light any Jeffersonville species in the shaly Onondaga of Pennsylvania. So far as now known, the 35 Ostracoda of the Jeffersonville of Kentucky and the 40 of the Onondaga of Pennsylvania have no more than one species in common, and even this one is questionably identified. The possibility of provincial and facies differences must of course be kept in mind; it is most likely, however, that the notable dissimilarities of the ostracode assemblages involve an appreciable variance in age.

COMPARISONS WITH OSTRACODES FROM HAMILTON SHALE IN NEW YORK AND ONTARIO AND MIDDLE DEVONIAN OF MICHIGAN AND OHIO

A few Ostracoda were described from the Middle Devonian Hamilton shale of New York and Ontario by Hall and Jones as early as 1862 and 1890, respectively. Papers by Turner (1939) and especially by Coryell and Malkin (1936) have added greatly to knowledge of species of the Hamilton of Ontario. Ostracoda of the essentially equivalent Traverse beds of Michigan and of the Silica shale of Ohio have been described by Warthin (1934), Van Pelt (1933), and Stewart (1936). None of the described assemblages is comparable to that of the Onondaga beds of Pennsylvania. Such Hamilton—Traverse species as *Ulrichia conradi, U. fragilis, Bollia hindei, Ctenoloculina cicatrosa,* and *Euglyphella projecta* exhibit rather close affinities to *Ulrichia pluripuncta, U. elongata, Bollia diceratina, Ctenoloculina punctocarinata,* and *Euglyphella* sp. of this paper, respectively. But such genera as *Hollinella, Ropolonellus, Rudderina, Spinovina, Quassellites,* and *Jenningsina,* though more or less abundantly represented in the Hamilton—Traverse beds, are not yet known in the Onondaga of Pennsylvania. Conversely, species referable to *Thlipsura, Ranapeltis, Stibus,* and *Favulella* have not been found in the Hamilton—Traverse horizons.

The Ostracoda of the Onondaga shaly limestone of Pennsylvania appear to be about as close to those of the Lower Devonian Shriver beds as to those of the Hamilton and Traverse. This fact, the extensive development of hollinellids in the Jeffersonville limestone, and the reported occurrence in the Hamilton—Traverse beds of the Jeffersonville species *Ctenobolbina papillosa* and *Amphissites subquadratus,* together with the previously discussed differences between the ostracodes of the Jeffersonville and those of the Onondaga of central Pennsylvania, all suggest that the latter beds are somewhat older than the Jeffersonville limestone.

It is not yet clear how the differences between the Ostracoda of the Jeffersonville and of the Onondaga beds of Pennsylvania may affect correlations with the type Onondaga limestone of New York. Whether, for instance, the Jeffersonville is younger than the type Onondaga involves data provided by nonostracode groups, and no review of this evidence has been attempted by the writers. In any event, significant information might be brought to light by studies of ostracodes of the New York deposits.

COMPARISONS WITH OSTRACODES FROM CAMDEN CHERT OF WESTERN TENNESSEE

A very interesting assemblage of Ostracoda from the lower part of the Middle Devonian Camden chert of western Tennessee has been described by Bassler (1941) in an article published as this paper goes to press. The faunule includes *Paraparchites mesleri,* with which our *Aparchites* (?)

lenticularis is evidently identical, together with *Parabolbina loculosa* and *Ranapeltis typicalis*, which are close to *Parabolbina parvinoda* and *Ranapeltis divergens*, respectively. On the other hand, the Camden chert congeries includes significant forms of pronounced Oriskany affinities, especially the species identified with *Bollia sagittaformis*, *B. burgeneri*, and *Thlipsurella secoclefta* of the early Oriskany Shriver chert of Pennsylvania. It lacks the typical Bollias of the Onondaga of Pennsylvania, as well as representatives of *Favulella* and *Stibus*. Because of these and other differences, and especially in view of the persistence in the Camden of the Oriskany elements, it is clear that the ostracode faunules of the Onondaga of central Pennsylvania are distinct from and appreciably younger than that described from the Camden chert.

SUMMARY OF STRATIGRAPHIC VALUE OF ONONDAGA OSTRACODES

As has been shown, the ostracodes of the Onondaga of central Pennsylvania are abundant and distinctive. They undergo changes within the formation so that four reasonably distinct zones can be recognized, at least near New Bloomfield.

The ostracodes of the Onondaga of central Pennsylvania appear to be distinctly younger than those described from the Middle Devonian Camden chert of western Tennessee. They differ from the ostracodes so far described from the Onondaga of New York, but too little is known of the latter to justify any positive conclusions at the present time. They are also distinct from and apparently older than the large suite of ostracodes of the Jeffersonville limestone of Kentucky, which has rather generally been regarded as a western correlate of the Onondaga of New York. In any event, use of ostracodes to more accurately establish the relations between the Onondaga of central Pennsylvania and the deposits of New York presents a promising field for investigation, and close equivalence of the Onondaga of central Pennsylvania with the type Onondaga of New York should not be taken too much for granted. The ostracodes offer valuable tools for stratigraphic work in these Middle Devonian sediments.

ORIENTATIONS USED FOR DESCRIPTION

The anteroposterior orientation of Paleozoic Ostracoda has been extensively discussed in recent years (for reviews, *see* Bonnema, 1932; 1934; Geis, 1932; Swartz, 1936) but continues to be a subject thorny with uncertainties. Because of this confusion, it is unfortunate that presentation of specific and generic characters is not feasible without constant reference to "anterior" and "posterior" ends, and "right" and "left" valves. In the following systematic descriptions, the orientations of

straight-backed forms used by Swartz in 1936 are continued; but there is no intention to suggest that they are clearly established. They generally follow the conception that the anterior cardinal angle tends to be less extended than the posterior and that in this respect the "swing" of the carapace tends to be anterior rather than posterior in direction. This view is favored by comparisons with shapes of modern Ostracoda (*see* Geis, 1932; Bonnema, 1932; 1934) as well as by the fact that it places the kloedenellid type of dimorphic swelling at the posterior end of the carapace (Swartz, 1933). Carried over to the beyrichiids, this orientation places their dimorphic pouches toward the anterior end, a position which if correct is as strange from the point of view of the higher vertebrates as is the location of the renal ducts of the common crayfish.

Orientation of the convex-backed Ostracoda presents a separate and equally troublesome problem. In *Thlipsura*, for instance, Jones regarded the thicker end as being posterior and, because of the depression at this end, proposed the name meaning "compressed tail". Ulrich and Bassler reversed this orientation, without explanation insofar as the writers know; as held by them, the anterior end of *Thlipsura* is much extended beyond the hinge. This is also the case in convex-backed Cretaceous and Tertiary cytherids when oriented by comparison with closely related modern species (*see* Alexander, 1933; Stephenson, 1937; 1938). The more complete opening of the anterior end, at least in the cytherids, may be an adaptation more favorable to extension of the antennae and especially the antennules.

In the Cretaceous and Tertiary cytherids, the adductor muscle lies well in front of the middle, as has been noted by Bonnema for modern Ostracoda in general. Two factors suggest themselves as possible reasons for this observed condition. In the first place, the anterior position may be favored by the greater extension of the carapace beyond the anterior end of the hinge in modern types, and insofar as this is a cause the adductor would tend to be less excentric where the carapace ends are more equal in terms of the hinge position. Secondly, it might be that the anterior position of the adductor is primarily a response to the tendency of the water to spread the front end of the opened valves as the ostracode swims forward or faces into a current. This tendency is of course limited by the relatively feeble swimming strength of the creature; but may have an appreciable value in terms of the strength of the adductor, and would probably be less affected by the hinge position. The tendency might even be overcome if the valves are curved in such a fashion that the net result of the water flow tends to force them together. It is difficult to evaluate the importance of such factors; however, the position of the adductor in modern forms is pre-

sumably a response to the mechanics of swimming and of carapace structure, and insofar as the same factors were effective in Paleozoic forms the position of the adductor is significant for orientation.

In the present paper, the convex-backed species have in general been described so that the more extended and frequently higher end is anterior. The position of the adductor scar has been regarded as significant where it is satisfactorily shown and where the evidence provided by shape and hinge position is more equivocal. In the special case of *Cavellina*, the terminal internal dimorphic chambers have been considered indicative of the posterior end.

CLASSIFICATION

Subsequent to the preparation of most of the section of this paper dealing with systematic descriptions, Kay (1940) has published an excellent discussion of Decorah Ostracoda in which he adopts a classification differing in important respects from the one which was advanced by Swartz in 1936 and is here used. It has not been possible to give his arrangement adequate consideration at this time. It is probably true that we have not yet reached a stage where a reasonably final classification of Paleozoic Ostracoda can be attained, and the family versus subfamily ranking of such groups as the aechminids, drepanellids or bolliids, and tetradellids is a matter of opinion and to some extent of convenience. More fundamentally, however, it is the opinion of Swartz that Kay's return to primary emphasis on the degree or strength of lobation is an undesirable and backward step and leads to unnatural assemblages, especially with respect to the beyrichiids, eurychilinids, and tetradellids.

SYSTEMATIC DESCRIPTIONS

Family LEPERDITELLIDAE Ulrich and Bassler

Genus *Aparchites* Jones

Aparchites (?) lenticularis Swartz and Swain, n. sp.[8]

(Plate 1, figure 1a-e)

Leperditia (?) subrotunda Kindle, 1912, U. S. Geol. Survey, Bull. 508, p. 115, Pl. 9, fig. 7; not *Leperditia (?) subrotunda* Ulrich, 1891, Jour. Cincinnati Soc. Nat. Hist., vol. 13, p. 181, Pl. 16, figs. 1a-c.

Carapace subcircular to somewhat ovoid in side view, the ventro-anterior margin tending to be somewhat extended; truncated dorsally by a short hingeline, which is about half the length of the carapace, or less. Hingement apparently involves some thickening of the hinge edges of both valves; overlap uncertain, but free edges are apparently thin and simple in left valve, thickened especially in the ventral part in the right valve. Whether the right valve overlaps the left, or whether the thin

[8] The species here described as *Aparchites (?) lenticularis* appears to be identical with *Paraparchites mesleri* Bassler (1941) of the Camden chert.

edge of the left valve simply fits against but not inside the thickening of the edge of the right valve, is not clear from the material now available.

Surface of valve moderately convex, smooth, without flattened portions, and without any appreciable dorsal projection or umbo. One internal mold, illustrated with this species (Fig. 1e) but very likely not belonging here, shows the impression of a well-marked muscle scar, with pits corresponding to rounded, rather regularly spaced papillae. No trace of muscle scars is visible on the well-preserved internal molds unquestionably belonging to this species.

Length 1.4 mm., height 1.2 mm.

RELATIONSHIP: Kindle in 1912 referred the species here described to *Leperditia (?) subrotunda* Ulrich, now placed in *Paraparchites* by Bassler and Kellett (1934). As illustrated and described by Ulrich, however, *P. subrotundus* has a relatively long straight hinge, about two-thirds the length of the valve and almost equal to its height, and is marked by a well-defined and fairly broad marginal flattening which encircles the valve except along the ventral edge.

OCCURRENCE: *Aparchites (?) lenticularis* is common 5 to 10 feet above the base of the Onondaga beds at Clarks Mill and fairly common 75 feet above their base at Mount Rock, Pennsylvania. Kindle illustrated a specimen from the Onondaga beds at Little Moccasin Gap, Virginia, and also reported it from the Onondaga at Hollidaysburg and Upper Reese, Blair County, Pennsylvania, and Berkeley Springs, West Virginia.

Family AECHMINIDAE Swartz

Genus *Aechmina* Jones and Holl

Aechmina crassicornis Swartz and Swain, n. sp.

(Plate 1, figure 3a-d)

Carapace in side view and without dorsal spine subelliptical, truncated by the straight hinge; cardinal angles about equal; hingement and overlap unknown.

Surface of valve gently convex, with a low, nearly obsolescent marginal ridge along the free edges, fainter ventrally than along the ends. Dorsomedian spine thick, fairly long, set a little in front of middle. Surface otherwise smooth.

The internal mold shown in Figure 3c measures length 0.84 mm., height 0.5 mm., without spine.

RELATIONSHIPS: *Aechmina crassicornis* has a faint marginal ridge, suggestive of the stronger ridge characteristic of *Paraechmina;* but it lacks the submedian pit of typical members of that genus. In this respect, it is similar to *A. marginata* Ulrich (1891) of the Hamilton of New York. The latter species has a much longer spine.

OCCURRENCE: Common in Onondaga beds 5 to 10 feet above base of Onondaga at Clarks Mill, and 75 feet above base at Mount Rock, Lewistown, Pennsylvania.

Aechmina (?) fimbriata Swartz and Swain, n. sp.

(Plate 1, figure 2a-d)

Carapace in side view and without dorsal spine subelliptical, truncated dorsally by the straight hinge line, which is about three fourths of the greatest length. Ends and cardinal angles about equal. Hingement and overlap unknown.

General surface of valve gently convex, except for a narrow, rather sharply deflected slope along all of the free margins; the angulation thus produced bears a number of spinelets, apparently becoming weak or absent along the ventral margin; the anterior spinelets at least are long and slender and are only slightly divergent from the conjunction plane of the valves; the posterior spines are

probably similar, but, in order to preserve part of the margin of the single mold so far obtained, the impressions of the posterior spines were not uncovered. The large spine is situated close to the dorsal margin; its base rises abruptly from the surrounding valve surface, but the character and length of the remainder of the spine are unknown. Just posterior to and a little below the base of this spine is a well-defined pit. The general surface of the valve, not including the spine, the pit, and the deflected marginal slope, is very finely pustulose.

Length 1.4 mm., height 0.8 mm., not including spine.

RELATIONSHIPS: Because of the paraechminid submedian pit, but absence of a marginal ridge, *A.* (*?*) *fimbriata* might be referred to *Aechminaria* Coryell and Williamson (1936). The genotype of *Aechminaria*, however, seems to be a paraechminid modified by obsolescence and in which the marginal ridge has been lost and the dorsomedian spine much reduced. *Aechmina* (*?*) *fimbriata* is of a type comparable to *A. spinoterminata* Swartz and *A. bigeneris* Swartz (1936), in which a paraechminid pit is retained, and submarginal spinules occur, probably by modification rather than obsolescence of the marginal ridge. The dorsomedian spine is strongly developed. These species can consequently be regarded as having resulted from a type of evolutionary development distinct from that which gave rise to *Aechminaria*.

The relations of these marginally spinose forms with the submedian pit need further investigation; and of course the spinelets may have risen in several distinct lines of descent. One of the first requirements is restudy of the marginally spinose *Aechmina cuspidata* Jones, the genotype, to confirm the supposed absence of the submedian pit in that species.

OCCURRENCE: Very rare, 5 to 10 feet above base of the Onondaga beds, Clarks Mill, Pennsylvania.

Family DREPANELLIDAE Swartz

Genus *Bollia* Jones and Holl

Bollia ungula Jones

(Plate 2, figure 4a-i)

Bollia ungula (Claypole ms.) JONES (part), 1889, Am. Geol., vol. 4, p. 338, Fig. 10, not figs. 11-13—KINDLE (part), 1912, U. S. Geol. Survey Bull. 508, p. 113, Pl. 9, Fig. 9, not Fig. 10—ULRICH AND BASSLER (part), 1913, Md. Geol. Survey, Middle and Upper Devonian, p. 336, Pl. 44, Fig. 7, not Fig. 8—SWARTZ, 1936, Jour. Paleont., vol. 10, p. 577, Pl. 88, Figs. 5a-c—WARTHIN, 1936, Wagner Free Inst. Sci., Beyrichiacea, No. 48, Figs. 10, 5a, b.

Possibly *Bollia ungula* ULRICH, 1891, Jour. Cincinnati Soc. Nat. Hist., vol. 13, p. 188, Pl. 14, Figs. 6a, b—ULRICH and BASSLER, 1908, U. S. Nat. Mus., Pr., vol. 35, p. 288—BASSLER, 1911, in CLELAND, Wis. Geol. Nat. Hist. Survey, Bull. 21, p. 143, Pl. 44, Fig. 5.

Carapace subquadrate to fairly elongate, generally somewhat extended anteroventrally. Hingement and overlap unknown.

Marginal ridge with flattened summit, the outer edge of the flattened area forming an angulation which tends to overhang the free edge anteroventrally; the angulation well marked and extending from near the anterodorsal angle to the postventral region, then dying out posteriorly. Inner U-shaped ridge much elevated, separated from marginal ridge by a narrow, shallow groove; limbs subvertical, each with a small, almost spinelike node at its dorsal end; anterior limb rounded, somewhat more swollen than the posterior one; beginning near ventral end of the anterior limb, a crest or angulation extends along the summit of the narrow ventral

bend, then curves upward along the outer part of the somewhat flattened summit of the posterior lobe, about halfway to its dorsal end. Surface of valve apparently without fine ornament.

A large, relatively subquadrate valve measures length 1.45 mm., height 1.0 mm.; a more elongate one measures length 1.6 mm., height 0.9 mm.

RELATIONSHIP: Study of new topotype collections has brought out the presence of (a) the small nodes at the dorsal ends of the limbs of the inner U-shaped ridge; (b) the persistent flattening and angulation of the marginal ridge.

Reported occurrences of *Bollia ungula* in the Jeffersonville limestone of Kentucky must be confirmed by new studies of collections from those beds. Swartz (1936) has elsewhere shown that the Shriver species previously referred to *B. ungula* is specifically distinct from the New Bloomfield topotypes.

The name *Bollia ungula* was first listed by Claypole in 1885, but without description or illustration. In 1889, Jones mentioned Claypole's work, and Warthin suggests that the species should be credited to Claypole rather than to Jones.

OCCURRENCE: Abundant 25 to 30 feet above base of Onondaga beds at New Bloomfield, Pennsylvania.

Bollia platyloba Swartz and Swain, n. sp.

(Plate 2, figure 5a-g)

Closely similar to *Bollia ungula* in size, variations in shape, flattening and angulation of the marginal ridge; also in characters of the inner U-shaped ridge, except that the angulation of the outer part of the summit of the posterior limb continues to the dorsal terminus of the limb, flattening the summit of this limb throughout its length. The spinelike nodes of the dorsal ends of the inner ridge tend to be a little weaker than in *B. ungula*.

The holotype measures length 1.44 mm. (about 1.5 mm. if posterior edge were fully restored), height 1.0 mm.

RELATIONSHIPS: *Bollia platyloba* occurs very sparingly with *B. ungula* about 25 feet above the base of the Onondaga at New Bloomfield, then becomes abundant at 65 feet where *B. ungula* has disappeared. *B. platyloba* is likewise abundant 75 feet above the base of the Onondaga at Mount Rock, where *B. ungula* is unknown. Because of this stratigraphic significance and zonal value, *B. platyloba* has been regarded as a distinct species rather than merely a variety of *B. ungula*. The two are, however, very closely related, and there is uncertainty as to which of the two forms was actually in Jones' hands when he described *B. ungula* in 1889.

OCCURRENCE: Very rare 25 feet, abundant 65 feet, rare 80 feet above base of Onondaga beds at New Bloomfield; abundant at Mount Rock, common at Warren Point, Pennsylvania; rare to common at Cooper Mountain, West Virginia.

Bollia hindei Jones

(Plate 3, figure 5a-f)

Bollia hindei JONES, 1890, Geol. Soc. London, Quart. Jour., vol. 46, p. 540, Pl. 20, Fig. 2—CORYELL AND MALKIN, 1936, Am. Mus. Novitates, No. 891, p. 2, Fig. 3—WARTHIN (part), 1937, Wagner Free Inst. Sci., Beyrichiacea, No. 41, Figs. 3, 4, 5, not 5a-c.

Possibly *Bollia widderensis* CORYELL AND MALKIN, 1936, Am. Mus. Novitates, No. 891, p. 2, Figs. 4, 4a.

Carapace subovate in side view, truncated dorsally by straight hinge line about two thirds of greatest length; cardinal angles obtuse, about equal; margin somewhat extended postventrally. Left valve in one specimen with well-defined groove along

whole length of hinge; one well-preserved right valve shows a well-developed rabbet inside the free edge and evidently receives and overlaps the free edge of the left valve.

Surface with a rounded marginal ridge, which is well developed and rises sharply from the free edge along the anterior and ventral margins, where it is separated from the inner ridge by a rather narrow, shallow furrow; the marginal ridge becomes nearly or quite obsolete posteriorly, where the surface rises rather sharply from the free edge, then passes into a broad gently convex area which rises toward the margin of the inner ridge. Inner ridge with well-developed knobs at the dorsal end of each limb; the anterior knob oval, a little wider below than above, the summit rounded, tending to decline toward the hinge; posterior knob lying close to hinge margin, smaller than anterior knob, rounded in plan view, elevated, the summit extended into a small conical protuberance. Yoke broad postventrally; narrowed anteroventrally, where it joins the anteroventral part of the anterior knob. Surface strongly papillose.

A fairly large valve measures length 1.47 mm., height 0.98 mm.

RELATIONSHIPS: The above description is based on study of 11 finely preserved valves from the Ulrich and Bassler collections in the United States National Museum. They were obtained in Moscow beds of the Middle Devonian Hamilton group at Thedford, Ontario, and are largely free of matrix except in the inner cavity of the valve. The hinge and overlap relations are of interest and have not previously been recognized.

Bollia widderensis was described by Coryell and Malkin as differing from *B. hindei* in its greater length. Warthin suggests that the two forms are sex dimorphs. Two clearly defined types are not seen in the specimens from the National Museum, and the writers do not feel sure of the significance of the reported differences in length. In the closely related *B. diceratina*, possible sex dimorphism is suggested by differences in convexity, chiefly in the posterior half of the valve as here described. There are also larger and shorter individuals which are here regarded as variants within the species.

Warthin reports that the holotype of *B. hindei* is missing from the collections in the British Museum.

OCCURRENCE: Jones' material came from the Hamilton at Eighteen Mile Creek, New York. The material described by Coryell and Malkin came from the Widder beds of the Hamilton near Arkona, Ontario; that illustrated in this paper was collected from Moscow beds near Thedford, Ontario.

Bollia obesa Ulrich

(Plate 3, figure 4a, b)

Bollia obesa ULRICH, 1891, Jour. Cincinnati Soc. Nat. Hist., vol. 13, p. 189, Pl. 14, Figs. 5a-c.

Bollia hindei WARTHIN (part), 1937, Wagner Free Inst. Sci., Beyrichiacea, No. 41, Figs. 5a-c, not Figs. 3-5.

Not *Bollia obesa* KINDLE, 1912, U. S. Geol. Survey Bull. 508, p. 114, Pl. 9, Fig. 8.

Carapace subelliptical to slightly subovate in side view, truncated dorsally by the straight hinge which is a little more than two thirds of greatest length; cardinal angles obtuse, about equal. Margin a little more extended postventrally than anteroventrally. Hingement and overlay unknown.

Valve with rounded marginal ridge, extending from angle to angle, rising rather sharply from free edge, about equal in height throughout, separated from inner ridge by a rather narrow, fairly shallow, rounded furrow, somewhat better defined

anteriorly than elsewhere. Inner U-shaped ridge with an elevated knob at each end, their summits rounded; anterior knob elongated, declining toward hinge; posterior knob smaller, round in plan view, situated close to hinge. Yoke about half as high as knobs; broad and somewhat inflated postventrally, narrower and lower anteroventrally, where it joins the anteroventral part of the anterior knob; this produces a strong anterior bend in the ventral part of the enclosed sulcus, as in *Bollia hindei* and *B. diceratina*. No fine ornamentation preserved.

The specimen here figured measures length 1.0 mm., height 0.68 mm. Ulrich reported length 1.52 mm., height 0.98 mm.

RELATIONSHIPS: Ulrich's holotype in the Ulrich and Bassler collections at the United States National Museum was examined, together with topotypes in that collection, presumably identified by Ulrich. One of the latter, closely similar to the holotype, is figured in this paper. The specimens are silica replacements, well preserved except for some marginal breakage. In none is there any trace of the peculiar conical protuberance seen in the posterior knob in *B. hindei*. The posterior parts of the marginal ridge and the adjacent furrow are markedly different in the two species. The apparent lack of pustulation in *B. obesa* may be significant but should be confirmed by further studies of Jeffersonville specimens. In view of the above differences, it is clear that *B. obesa* and *B. hindei* are not synonyms, as has been suggested by Warthin.

OCCURRENCE: Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky.

Bollia diceratina Swartz and Swain, n. sp.

(Plate 3, figures 1a-h, 2a-f)

Bollia obesa KINDLE, 1917, U. S. Geol. Survey, Bull. 508, p. 114, Pl. 9, Fig. 8—ULRICH AND BASSLER, 1913, Md. Geol. Survey, Middle and Upper Devonian, p. 337, Pl. 44, Fig. 9.

Not *Bollia obesa* ULRICH, 1891, Jour. Cincinnati Soc. Nat. Hist., vol. 13, p. 189, Pl. 14, Figs. 5a-c.

Carapace subovate in side view, truncated dorsally by straight hinge about two thirds to five sevenths of greatest length; cardinal angles obtuse, about equal; margin more or less extended post-ventrally. Hinge with longitudinal groove in left valve, apparently receiving thinner edge of right; right valve more or less rabbeted along free edge, apparently overlapping free edge of left.

Valve with a rounded marginal ridge along the anterior and ventral margins, where it is separated from the inner ridge by a shallow, rather narrow groove; the marginal ridge and adjacent groove tending to become obsolete posteriorly, where there is a rather broad gently convex area behind the inner ridge. Inner U-shaped ridge with an elevated knob at each end; posterior knob close to hinge, strongly elevated, the summit produced into a conical protuberance; anterior knob larger, oval, somewhat broader below than above, its summit tending to be rounded, but surmounted by a small conical node. Yoke very broad and somewhat inflated postventrally; narrowed anteriorly where it joins anteroventral portion of anterior knob; ventral end of enclosed sulcus bent forward around postventral part of anterior knob. Surface with well-developed crowded papillae, sometimes a little coarser on the marginal ridge in the anteroventral part of valve.

There is considerable variation in the convexity of the postventral third of the valves, especially as represented in the internal molds. The more convex individuals may be female dimorphs.

A large valve measures length 1.64 mm., height 0.96 mm.

RELATIONSHIPS: *Bollia diceratina* differs from *B. obesa,* with which it was formerly identified, in the conical protuberances of the knobs of the inner ridge and the posterior obsolescence of the marginal ridge and adjacent groove. Also, the yoke of the inner ridge is broader postventrally, and the surface is strongly pustulose. It is separated from the more closely related *B. hindei* by the small but persistent conical node of the anterior knob and also the distinctly greater width of the postventral portion of the inner ridge.

The comparative orientation of *Bollia diceratina* and of the other species of *Bollia* here described presents an interesting and special problem. Swartz (1936, p. 574) pointed out the difficulties encountered in orienting the Shriver *B. sagittaformis, B. burgeneri,* and *B. zygocornis.* In those species, there is not much difference in the cardinal angles, and the extension of the ends beyond the hinge is variable but not great. The orientation used for description was based on the supposed anterior position of the sulcus enclosed by the inner ridge; with this orientation, the anterior limb of the inner ridge is more swollen than the posterior limb, and the ventral end of the enclosed sulcus bends forward. The greatest height is behind the middle.

On the basis of the lobation, this orientation is readily applied to the Onondaga *B. planojugosa* and *B. spinomuralis.* Insofar as the cardinal angles are unequal, the posterior angle tends to be a little sharper than the anterior one. The ends project about equally; there is no pronounced swing to the carapace, although the greatest height in behind the middle.

The same features of lobation provide a clear basis for carrying the above orientation to *B. diceratina.* There is not much difference in the cardinal angles, but in this species the ends project unequally, and, with the above orientation, the postventral margin is much extended and there is a pronounced backward swing. The conditions are developed to a lesser degree in *B. hindei* and *B. obesa.*

In *Bollia ungula* there is also a strong swing to the carapace; but, using the lobation and position of the sulcus as above, the swing is anterior, not posterior, and the margin is most extended anteroventrally and not postventrally.

Whatever is done about the orientation of the above species of *Bollia,* it appears that lobation provides the best guide to orientation as between one species and another, and their orientation will have to be considered in terms of the group as a whole.

OCCURRENCE: *Bollia diceratina* is one of the most persistent and distinctive species of the Onondaga beds in the area here studied; it is common to abundant in the collections from Clarks Mill, Mount Rock, Newton Hamilton, and from 65 feet above base of the Onondaga at New Bloomfield, Pennsylvania; it is abundant at Cooper Mountain and rare at Berkeley Springs, West Virginia. *"Bollia obesa"* was reported by Kindle from Blair County, Pennsylvania; Cumberland and Tonoloway, Maryland; Ridgeville, West Virginia; Bells Valley and Little Moccasin Gap, Virginia; complete identity with *B. diceratina* will of course have to be determined by future studies.

Bollia diceratina var. *fimbriata* Swartz and Swain, n. var.

(Plate 3, figure 3)

Like *Bollia diceratina,* except that spinose projections occur on the marginal ridge in the anteroventral part of the valve. These appear to have been developed by enlargement and elongation of the normal surface pustules.

Length 1.25 mm., height 0.8 mm.

RELATIONSHIPS: In some of the specimens from Clarks Mill, here retained in *Bollia diceratina*, the surface pustules are in part somewhat enlarged on the marginal ridge in the anteroventral part of the valve. In the one specimen placed in the variety *fimbriata*, however, the difference in size between the spinose projections and the normal pustules is very marked, as is shown in the photographs.

OCCURRENCE: Very rare in Onondaga beds at Clarks Mill, Pennsylvania.

Bollia planojugosa Swartz and Swain, n. sp.

(Plate 4, figures 1a-g)

Carapace elongate subrectangular in side view, but somewhat higher behind than in front of middle; anterior angle obtuse; posterior angle tending to be somewhat produced. Hingement and overlap unknown.

Surface of valve with a well-developed marginal ridge, extending from angle to angle; ridge thickest anteriorly, where it is rounded and rises rapidly from free edge; much lower and narrower ventrally; higher again and fairly thick posteriorly, its summit flattened here, the flattened area sloping somewhat toward its inner edge, the outer edge of this summit rather sharply defined and tending to form an angulation; below this angulation the slope to the valve edge is concave, forming a fairly wide flange along the posterior margin. Inner ridge elevated slightly above outer ridge, from which it is separated by a narrow fairly deep groove; its summit is flattened, just a shade lower ventrally than above, and, as in the case of the outer ridge, it declines in approaching hinge; anterior limb expanded on the inner side, harpoon shaped, so that the enclosed sulcus has a pronounced anteriorly directed bend at its lower extremity; ridge narrowed anteroventrally, much thickened postventrally, then narrowing somewhat postdorsally. Flattening especially marked along the posterior limb of the ridge, tending to form an angulation between the summit and the steep inner and outer slopes. Surface marked by relatively distant, rounded to elongate, puncturelike depressions.

In the inner molds, the ridges appear to be much narrower and the furrows proportionately wider; the inner ridge is low ventrally, the harpoon-shaped anterior part appears swollen and lobelike. These differences in the mold and the valve exterior are in part the result of normal variation in radius of curvature of the outer and inner surfaces where the carapace is of uniform thickness but is bent in the ridges; in part, as in the case of the anterior lobe of the inner ridge, they evidently involve changes in thickness of the carapace.

The holotype measures length 1.58 mm., height 0.86 mm.

RELATIONSHIPS: In shape of carapace, character of lobation, and surface detail, *Bollia planojugosa* is very close to *B. sagittaformis* Swartz (1936, p. 574, Pl. 88, figs. 1a-f) of the Lower Devonian Shriver beds. It differs therefrom in the relatively greater width and flattening of the surface ridges and the corresponding and pronounced reduction in width of the grooves; also in the marked thickening of the postventral part of the inner ridge.

OCCURRENCE: Common at 65 feet, rare at 80 feet above base of the Onondaga at New Bloomfield; common at Mount Rock and Newton Hamilton, Pennsylvania; rare at Cooper Mountain and common at Berkeley Springs, West Virginia.

Bollia spinomuralis Swartz and Swain, n. sp.

(Plate 4, figure 2 (a-c))

Carapace elongate subrectangular in outline, hinge about seven eighths of greatest length; anterior angle rounded, posterior angle sharper though obtuse. Hingement and overlap unknown.

Valve with rounded marginal ridge, well developed and fairly high anteriorly and posteriorly, much lower and narrower ventrally; there is a fairly broad flange outside the ridge along the posterior margin, and the surface is also slightly concave outside the anterior part of the marginal ridge. At the postventral bend, the marginal ridge bears a strong blunt spine projecting outward and slightly downward. Furrow inside marginal ridge of moderate width and depth anteriorly and posteriorly, very narrow and shallow ventrally, where inner ridge is only a short distance from the ventral edge. Inner ridge low and weak except for a much elevated, rounded, anterodorsal knob, which lies a little below hinge margin; the ridge is broad ventrally and postventrally, but the posterior limb narrows and becomes obsolete before reaching the dorsal margin. No fine ornament is shown in the external molds. Lobation as seen on internal molds exceptionally close to the true external lobation.

Length 0.68 mm., height 0.43 mm.

RELATIONSHIPS: The spine of the postventral bend of the marginal ridge is a unique feature.

OCCURRENCE: Rare in Onondaga beds at Mount Rock, Lewistown, Pennsylvania.

Genus *Ulrichia* Jones

Ulrichia pluripuncta Swartz

(Plate 1, figure 4a-g)

Ulrichia conradi KINDLE, 1912, U. S. Geol. Survey, Bull. 508, p. 115, Pl. 9, Fig. 12; not *Ulrichia conradi* JONES, 1890, Geol. Soc. London, Quart. Jour., vol. 46, p. 544, Fig. 2.

Ulrichio pluripuncta SWARTZ, 1936, Jour. Paleont., vol. 10, p. 578, Pl. 87, Figs. 7a-f.

Carapace subquadrate to dorsally truncated subelliptical; posterior cardinal angle slightly produced. Overlap unknown, hinge apparently simple.

Surface of valve gently convex within a well-developed, rounded ridge which extends along the free edges; bearing near the dorsal margin two prominent, rounded knobs; anterior knob much the larger, set well in front of middle, separated from posterior knob by a well-defined sulcus; the narrow ventral end of sulcus extends about as far as the lower part of the anterior knob, to which it is closely adjacent. Area within marginal ridge, but not including the knobs and sulcus, marked by fairly distant, rather deep rounded pits, about 75 to 80 in number.

Average size about length 0.8 mm., height 0.48 mm.

RELATIONSHIPS: The Onondaga material described above agrees with typical *Ulrichia pluripuncta* of the Lower Devonian Shriver formation in general size, outline, inequality of the knobs, character of the pitting, and presence of a nonpitted sulcus. The sulcus especially distinguishes it from the Hamilton *Ulrichia conradi* Jones as described by Warthin (1934, p. 213; 1937, card No. 94), Stewart (1936), and by Coryell and Malkin (1936, p. 1; *U. spinifera* C. and M. = *U. conradi* Jones). Also, no marginal spinules such as those figured by Coryell and Malkin have been observed in the Onondaga specimens.

In 1936, Swartz suggested (1936, p. 579) that the form described as *Ulrichia terminata* might prove to be the dimorph of *U. pluripuncta*. No such form as *terminata* has been found with *pluripuncta* in the Onondaga beds.

Inclusion of *Ulrichia* in the Drepanellidae is very questionable. The genus may well have arisen from some such form as *Halliella* (?) *truncata* Coryell and Williamson (1936), quite independently of the Ordovician drepanellids.

OCCURRENCE: Fairly common 5 to 10 feet above base of Onondaga beds at Clarks Mill, very rare 65 feet above base at New Bloomfield, Pennsylvania. Kindle reported it from beds 40 to 50 feet above base of the Onondaga at McVeytown, Pennsylvania.

Ulrichia elongata Swartz and Swain, n. sp.

(Plate 1, figure 5a-c)

Carapace elongate subovate in side view, truncated dorsally by the long straight hinge; cardinal angles somewhat obtuse; margin more protruded anteroventrally than postventrally. Hingement and overlap unknown.

Surface moderately convex, the greatest convexity being toward the front; a low narrow ridge extends parallel to and near the anterior and anteroventral margins, then diverges from the margin and becomes obsolescent posteriorly; it seems to be represented again by a faint elevation near the dorsal margin, about one quarter the length of the valve from the postcardinal angle. Close to dorsal edge are two moderately elevated, rounded, unequal knobs; the smaller is dorsomedian in position and is separated from the larger, more anterior knob by a well-defined, narrow furrow, the narrow ventral end of the furrow being directed somewhat forward. In one specimen there is a faint ridge along the lower margin of this sulcus. Surface inside submarginal ridge, not including knobs and sulcus, marked by closely spaced, moderately coarse pits, which are also faintly represented posteriorly outside the obsolescent part of the submarginal ridge.

Length 0.6 mm., height 0.35 mm.

RELATIONSHIPS: In size, shape, location of the submarginal ridge, and close spacing of the dorsal knobs, *Ulrichia elongata* approaches *U. fragilis* Warthin (1934, p. 213) of the Middle Devonian Traverse group of Michigan. In the latter species, however the submarginal ridge is stronger, the dorsal knobs are pitted, and a sulcus is apparently not present.

OCCURRENCE: Fairly common in Onondaga beds, 75 feet above top of exposed Ridgeley sandstone, Mount Rock, Lewistown, Pennsylvania.

Family HOLLINIDAE Swartz

Genus *Parabolbina* Swartz

Parabolbina parvinoda Swartz and Swain, n. sp.

(Plate 1, figure 6a-j)

Carapace subovate in side view, truncated dorsally by the straight hinge which is a little less than greatest length; greatest height in front of middle. Postcardinal angle extended into a blunt projection; anterocardinal angle generally obtuse and simple as seen in internal molds; but the one external mold which really preserves this angle shows the impression of a long, upwardly directed spine, curving slightly to the rear. Hingement and overlap unknown.

Surface of valve rather strongly convex, marked a little in front of vertical midline by a fairly deep sulcus, extending less than halfway from dorsal to ventral margin, deepest ventrally and open dorsally. Upper part of sulcus constricted posteriorly by a low rounded swelling, which lies close to the dorsal margin; due to thinning of the carapace, this swelling is represented on internal molds by a more pronounced and almost knoblike rounded prominence. A less conspicuous, smaller swelling, more distant from the hinge, borders the sulcus on the front. Area below the sulcus is elevated, forming an indistinct longitudinally directed

bulge, roughly parallel to the postventral margin of valve. In most of the observed specimens, a wide but thin frill extends parallel to the margin from about halfway below the anterodorsal angle to a little behind the middle of the valve; it is marked on its outer or upper surface by three fairly deep grooves, which divide the frill into four arched sections; grooves correspond to partitions which divide the under part of the frill into four compartments. A small spine projects from the ventral slope in line with and a short distance behind the end of the frill. The frill is absent in some associated, less well-preserved molds, which presumably represent male dimorphs. In the external mold (*see* Fig. 6(d)) of one frilled individual, the free edge is seen to be slightly expanded, the expanded edge paralleled by a faint groove marked by close-set minute pits. General surface of valves, not including frill and sulcus, coarsely papillose.

The largest observed valve measures, without frill, length 0.8 mm., height 0.45 mm.; or, with frill, length 0.92 mm., height 0.56 mm.

Relationships: The closely related Lower Devonian *Parabolbina limbata* Swartz (1936, p. 571) is also dimorphic but lacks the distinct subdorsal swellings or nodes and has a small spine attached in the female to the postventral end of the frill. *P. parvinoda* is fairly close to *P. bifida* (*Tetrasacculus bifidus* Stewart 1936, p. 745) of the Middle Devonian Silica shale of Ohio, but the subdorsal nodes are more conspicuous, and the ventral forking of the sulcus is less pronounced.

Occurrence: Rare in Onondaga beds at Clarks Mill, Mount Rock, and Warren Point, Pennsylvania.

Genus *Ctenobolbina* Ulrich

Ctenobolbina (?) *ventricosa* Swartz and Swain, n. sp.

(Plate 2, figure 2a, b)

Carapace subovate in side view, truncated dorsally by straight hinge about eight ninths of greatest length. Anterior cardinal angle obtuse; posterior angle somewhat extended. Hingement and overlap unknown.

Surface of valve marked by an oblique sulcus which is open and flaring dorsally, is deepest just above center of valve, and has a shallow extension reaching almost to the anteroventral margin. Surface much elevated and forming an oblique swelling about parallel to, behind, and below the sulcus, the surface concave and forming something of a flange between this swelling and the postventral margin. Surface almost as much elevated anterior to sulcus, and also swollen and overhanging the free edge anteroventrally, the extension of the sulcus marking the surface of this area rather than dividing it. The crest of the overhang tends to be angulated, apparently not due to crushing, the angulation being especially strong and forming a small node just in front of the end of the sulcus.

On the internal mold, the prominence corresponding to the swelling parallel to and behind the sulcus is more marked than on the exterior of the valve, and, about one third the distance below dorsal margin, there is a low almost nodelike elevation on the anterior side of the sulcus representing a shallow excavation of the inside of the valve.

Surface of valve without fine ornament.

Length 0.7 mm., height 0.4 mm.

Relationships: The relationships of this species are not clear. Because of the ventral prolongation of the sulcus, it has been considered a member of the unisulcate division of *Ctenobolbina*.

OCCURRENCE: Rare in Onondaga beds at Mount Rock and Warren Point, Pennsylvania.

Family TETRADELLIDAE Swartz

Genus *Ctenoloculina* Bassler

Ctenoloculina punctocarinata Swartz and Swain, n. sp.

(Plate 2, figure 1a-c)

Carapace subelliptical in side view, dorsally truncated by the straight hinge, which is about equal to greatest length; anterior cardinal angle obtuse; posterior angle more prominent, about a right angle. Overlap unknown; hinge apparently simple.

Three fairly broad and deep sulci cross surface of valve from dorsal about to ventral margin; median sulcus deepened above; bent forward below, forming an almost sigmoidal curve. The sulci throw into relief four lobes of which the posterior one is much the broadest; anteromedian lobe subclavate, wider above, curving forward below. Surface of ridges marked by numerous fine puncta separated by narrow reticulations; the punctate surface in each case bordered on each side by a narrow rim. In the five or six specimens in the collections, the punctate ridges are wider in the left than in the right valves; that this is a true specific character needs further confirmation.

In all of the observed valves, the surface is expanded anteroventrally, forming a thin frill-like extension, seen in the lateral view of the valve as a moderately distinct swelling which carries the extensions of the surface lobes and sulci; on its under surface, the frill is divided by four narrow ridges into five deep compartments, so that the impressions of the ridges and compartments are conspicuous on the internal mold of the valve. The compartments are open to the exterior, insofar as the fossilized carapace is concerned, and do not show any connection to the inner cavity or living chamber of the carapace.

The figured internal mold of a right valve measures length 1.25 mm., height including frill 0.65 mm.

RELATIONSHIPS: The genus *Ctenoloculina* has been erected by Dr. R. S. Bassler (1941) in a paper dealing with ostracodes of the Camden chert of western Tennessee. The reader is referred to this source for a discussion of the generic characters.

C. punctocarinata is closely allied to *C. cicatrosa* (*Tetradella cicatrosa* Warthin) (1934) of the Middle Devonian Traverse beds of Michigan but has the lobes more abundantly punctate. Warthin describes dimorphs with and without the ventral frill and compartments, which he regards as brood chambers. Additional collections will probably show a similar dimorphism in *punctocarinata*.

The frill-like expansion and compartments in *C. punctocarinata* and *C. cicatrosa* strongly suggest the dimorphic frills and compartments of *Parabolbina* and of species of *Hollina* such as *H. cavimarginata* (Ulrich), and these relationships suggest that *Ctenoloculina* may belong with the Hollinidae rather than with Tetradellidae. However, somewhat similar submarginal loculi have been described in typical Ordovician species of *Tetradella* (Ulrich, 1891, Kay, 1934), and their dimorphic nature as suggested by Swartz (1936) has recently been confirmed by Kay (1940).

OCCURRENCE: Rare in Onondaga beds at Clarks Mill, Swatara Gap, Newton Hamilton, and Warren Point, Pennsylvania, and at Berkeley Springs, West Virginia.

Family Zygobolbidae Ulrich and Bassler

Subfamily Kloedeninae Ulrich and Bassler

Genus *Kloedenia* Jones and Holl

Kloedenia rectangularis Swartz and Swain, n. sp.

(Plate 2, figure 3a-c)

Carapace subrectangular in side view, the hinge a little less than the greatest length; anterior angle obtuse; posterior angle, overlap, and hingement unknown.

Surface of valve moderately convex, bearing just in front of middle a slightly oblique, subvertically elongated, sharply elevated median lobe, which extends more than halfway toward the ventral margin and does not reach the dorsal margin. Median sulcus flaring above, rather narrow and fairly deep below, nearly vertical, extending ventrally a little beyond the median lobe. Anterior sulcus much shallower, distinctly developed for only about one third the distance from the dorsal margin. Anterior lobe much broadened ventrally; posterior lobe broad, gently convex. Close to free edge is a very narrow low submarginal ridgelet; immediately adjacent to the free edge is a row of minute papillae. General surface within submarginal ridgelet and apparently not including the sulci and median lobe, marked by faint subpustules, about two in 0.15 mm.

Length 3.85 mm., height 2.53 mm.

Relationships: The general shape, proportions, and especially the elevated median lobe suggest the *Kloedenia* sp. of the Onondaga of New York, figured and described by Jones (1890, p. 538, Pl. 20, Fig. 1a, b) under the name *Beyrichia kloedeni* McCoy var. The latter, however, is apparently somewhat larger and is based on a female valve in which the brood pouch bears peculiar, strong, distant pustules. Unfortunately, no female valves have been found with the male specimen here figured and described, so that the characters of the brood pouch remain unknown, unless they may possibly be represented by Jones' valve.

Occurrence: Very rare in Onondaga beds at Cooper Mountain, West Virginia.

Kloedenia (?) fililimbata Swartz and Swain n. sp.

(Plate 8, figures 1a, b)

Carapace subquadrate in outline; hinge line long, about equal to greatest length; anterior angle slightly obtuse, posterior angle somewhat acute. Hingement and overlap unknown, but edge of valve about in one plane and overlap not pronounced.

Surface of valve moderately convex. Anterior lobe obsolete; median lobe rounded, moderately elevated, set well below dorsal margin, separated from posterior lobe by well defined median sulcus, which is open dorsally, and closes off ventrally about halfway from dorsal margin; posterior lobe most elevated along its anterior edge, this elevation tending to project slightly beyond hinge, and projecting ventrally almost to ventral edge, near which it curves anteriorly. Surface with rather distant, fairly shallow but coarse rounded pits; these are absent close to the free edge, where there is a border of radially directed, rather distant, fine threadlike elevated lines.

The holotype measures length 1.5 mm., height about 0.7 mm. A relatively higher mold which may be more truly representative of the proportions of the species measures length 1.48 mm., height 0.92 mm.

Relationships: *Kloedenia (?) fililimbata* is known from molds of only two halves, both of which presumably represent males. The character of the lobation is some-

what suggestive of *Treposella*, but there is no trace of a frill such as should occur in that genus, and lacking the evidence which would be provided by the dimorphic pouch, it seems best to refer *fililimbata* to *Kloedenia*.

OCCURRENCE: Very rare 80 and 100 feet above base of the Onondaga beds, New Bloomfield, Pennsylvania.

Family KIRKBYIDAE Ulrich and Bassler

Genus *Amphissites* Girty

Amphissites (?) *altireticulatus* Swartz and Swain, n. sp.

(Plate 4, figure 3a-i, Plate 8, figure 2)

Carapace subovate to subrhomboidal in side view; hinge straight, about two thirds greatest length; greatest height behind middle; posterior angle obtuse but more prominent than anterior. Molds indicate right valve has along free edge a shallow rabbet to receive edge of left valve; special hinge structures not recognized in the molds. The overlap relations need further confirmation.

Surface rather strongly convex, rising fairly steeply from ventral, not quite so steeply from dorsal margin; bearing anteromedially a strong deep kirkbyid pit with a continuous rim; carapace very thin, with thin but highly elevated reticulations which enclose coarse deep polygonal to rounded pits, of which there are typically 2 or sometimes 3 in 0.2 mm. The pits tend to be arranged concentrically about the kirkbyid depression and parallel to margins; they are much reduced in size in the rows close to the margins. Along the free edges of the left valve, at least, there is a very narrow nonpitted border, widened a little ventrally, possibly to fit into rabbet of right valve.

On the internal molds, there is a deep depression corresponding to the kirkbyid pit; above this is another shallow hollow of slightly smaller diameter; anterodorsally to the kirkbyid depression is a low faint rounded swelling, representing a slight excavation of the interior of the valve. The general surface pitting is not appreciably reflected in the internal molds.

The holotype measures length 1.8 mm., height 1.1 mm., convexity 0.45 to 0.5 mm.

RELATIONSHIPS: In its strong kirkbyid pit, coarse reticulations, and lack of ridges and shoulders, this species differs markedly from *Amphissites rugosus* Girty, the genotype. In many respects it approaches *Savagella lindhali* (Ulrich), the genotype of *Savagella* Geis (1932, p. 168), but one of the most important characteristics of *Savagella* as defined by Geis is the overlap along the free edges of the left valve, as here defined, over the right. Because of the apparent direction of overlap, and since the species currently included in *Amphissites* exhibit a wide variation in development of the submedian pit, the surface reticulation, and the shoulders or ridges, *altireticulatus* has been left in the genus for the present.

In the typical specimens from 25 feet above the base of the Onondaga at New Bloomfield and from the lower Onondaga at Clarks Mill, the surface pits near the middle of the valve measure about 2 in 0.2 mm. These do not vary much in smaller, immature specimens, one valve only 0.7 mm. in length having 3 pits in 0.2 mm. In material from higher parts of the Onondaga the pits are somewhat smaller. Thus in specimens from 100 feet above the base of the Onondaga at New Bloomfield there are 3 to 3½ or sometimes 4 pits in 0.2 mm.; at 75 feet at Newton Hamilton there are 2½ to 3 in 0.2 mm.; at 85 to 90 feet at Berkeley Springs the pits are rather persistently about 3 in 0.2 mm., a few being finer but none coarser so far as observed.

Amphissites (?) altireticulella is somewhat suggestive of *A. ulrichi* Bassler (1941) of the Camden chert; but the latter apparently is less convex and seems to have a narrow submarginal ridge.

Occurrence: Common 25, 80, and 100 feet above base of the Onondaga at New Bloomfield, 5 to 10 feet above base at Clarks Mill, and 75 feet above base at Newton Hamilton; rare and questionable at Swatara Gap, Pennsylvania; abundant 85 to 90 feet above base at Berkeley Springs, West Virginia.

Amphissites (?) altireticulella Swartz and Swain, n. sp.

(Plate 8, figure 3)

Carapace suboval to subovate in outline; hinge line straight, about two thirds greatest length; posterior angle obtuse, more prominent than anterior. Hingement and overlap unknown.

Surface rather strongly convex, bearing submedially a strong deep kirkbyid pit with a narrow rim. Carapace very thin with thin rather high reticulations which enclose fine rounded to somewhat polygonal pits; the pits show an imperfect tendency toward concentric arrangement; they are small, about 5 in 0.2 mm.; they become obsolete close to the free edges leaving a narrow border.

The holotype measures length 0.97 mm., height 0.6 mm. Larger specimens reach lengths of 1.25 mm. or a little more.

Relationships: This form is very close to *Amphissites (?) altireticulatus,* but the pitting is much finer, about 5 or even 6 pits in 0.2 mm. as compared to 2 in the typical material, or 3 to occasionally 4 in 0.2 mm. in the specimens from higher parts of the Onondaga which are here regarded as variants within *altireticulatus.* The difference in size is not an ontogenetic change.

Two of the specimens included in *altireticulella,* one from Newton Hamilton and one from 100 feet above the base of the Onondaga at New Bloomfield, exhibit a peculiar structural feature which may prove important with examination of further collections. In these individuals, two rows of pits along the ellipse, longitudinally elongate with upper limb a little above the kirkbyid depression, are so arranged that the ridges separating adjacent pits are continuous perpendicular to the rows. As seen in the external molds, this structure shows up as an ellipse of narrow, transversely directed clefts. A similar arrangement develops along the dorsal margin but is there somewhat less conspicuous.

Occurrence: Rare to common 100 feet and 80 feet above base of the Onondaga, New Bloomfield, and 75 feet above base, Newton Hamilton, Pennsylvania.

Genus *Kirkbyella* Coryell and Booth

Kirkbyella rhomboidalis Swartz and Swain, n. sp.

(Plate 4, figure 4a-c)

Carapace elongate subrhomboidal to subrectangular, posterior angle obtuse but more extended than the anterior. Hinge apparently simple; overlap unknown.

Surface of valve marked by a sulcus which lies a little in front of and above middle of valve and tends to be pitlike but is open dorsally. Below the sulcus is a strong longitudinal swelling or elevation, merging into the general surface at its anterior end but ending abruptly at its elevated posterior terminus. Elsewhere, the valve is only moderately convex. Surface marked by small rounded, fairly distant pits.

The holotype measures length 0.65 mm., height 0.32 mm., maximum convexity 0.15 mm.

RELATIONSHIPS: *Kirkbyella rhomboidalis* is fairly close to the Middle Devonian *K. bellipuncta* (Van Pelt, 1933 p. 332) and *K. unicornis* Coryell and Malkin (1936, p. 5). The first, however, has a smooth marginal border, and the ventral ridge is costate; the second has a reticulate surface, with finer and more close-set pits than in *K. rhomboidalis*.

OCCURRENCE: Rare in collections from Onondaga beds at Clarks Mill and Mount Rock, Pennsylvania.

Family THLIPSURIDAE Ulrich

Genus *Thlipsura* Jones and Holl

Thlipsura thyridioides Swartz and Swain, n. sp.

(Plate 4, figure 5a-j)

Carapace subovate to subreniform in side view, the dorsal margin strongly convex, ventral margin nearly straight, the anterior margin more broadly rounded than the posterior. Hingement and overlap not shown on specimens studied.

Surface of valve strongly convex; marked at anterior end by a fairly broad depressed area, whose floor, however, rises steeply from the valve edge. A cleft extends a short distance posteriorly and slightly upward from the lower part of the depressed area; it is separated from the ventral edge of the valve by an elevated ridge that juts forward to the anteroventral bend of the valve but is posteriorly continuous with the general surface. Posterior to the margin of the depressed area are two subvertical clefts—the "little windows" of the specific name. The first cleft is somewhat farther from the dorsal margin than the other and is separated from the depressed area by a very narrow ridge, generally somewhat less elevated than the general surface; the second is a little closer to the dorsal margin and is separated from the first by a moderately broad area, continuous with the general surface of the valve, but tending to slope slightly toward the posterior cleft. Surface apparently without fine detail.

In the internal molds, the furrow corresponding to the posterior subvertical cleft tends to connect with that representing the horizontal cleft; this represents a thickening of the interior of the carapace [illegible] in some specimens bears a suggestion of a muscle scar. A slight internal thi[illegible] also extends dorsally from the dorsal end of the posterior subvertical cleft.

Length 0.9 mm., height 0.6 mm.

RELATIONSHIPS: *Thlipsura thyridioides* is one of the more important and distinctive Ostracoda of the Onondaga beds of the region studied. It apparently developed out of the Shriver *T. confluens* Swartz by obsolescence of the furrow which in that species connects the dorsal ends of the subvertical clefts with one another and with the anterior depressed area.

OCCURRENCE: Rare 80 feet, common 25 feet above the base of the Onondaga at New Bloomfield, common at Mount Rock and Newton Hamilton, rare at Warren Point, Pennsylvania; common at Cooper Mountain, very rare at Berkeley Springs, West Virginia.

Thlipsura sp.

(Plate 5, figure 1)

Carapace subovate to subreniform in side view; dorsal margin strongly arched, highest a little in front of middle; ventral margin nearly straight. Hingement and overlap unknown.

The species is known from the internal molds of two valves, which exhibit the following features: surface rather strongly convex; marked along anterior margin by a rather wide depressed area, which slopes fairly steeply to the edge; a cleft extends posteriorly for some distance from the ventral part of the depressed area; a second cleft extends posteriorly from the more dorsal part of the depressed area and just before reaching the vertical midline of the valve bends abruptly downward, ending suddenly just in front of the center of the valve. The elevated area lying between the two clefts has a short anterior extension at its anteroventral angle. The surface of the mold is a little depressed between the distal ends of the clefts, so as to suggest a muscle scar; the ridge above the longitudinal part of the upper cleft is elevated distally, somewhat depressed proximally, and tends to be separated from the valve edge by a faint extension of the anterior depressed area.

Length 1.12 mm., height 0.68 mm.

RELATIONSHIPS: Clear development of the longitudinal part of the upper furrow shows that this is not the *Thlipsura thyridioides* of the Onondaga beds at New Bloomfield, Mount Rock, and Cooper Mountain. The anteroventral extension of the elevated area lying between the clefts suggests the proximal part of the low ridge which in the Shriver *T. confluens* extends forward and then abruptly upward to enclose an anterior subvertical furrow. No such ridge is clearly shown in the internal molds here described. In the photograph there is a suggestion that on the exterior the upper cleft may have the form of an inverted U; but this is less clearly indicated on the mold as seen under the binoculars. This is probably a new and distinct species, but its characters will have to be more certainly determined by discovery of external molds.

OCCURRENCE: Rare in Onondaga limestone, Swatara Gap, Pennsylvania.

Genus *Octonaria* Jones

Octonaria stigmata Ulrich

(Plate 5, figure 2a-c)

Octonaria stigmata ULRICH, 1891, Cincinnati Soc. Nat. Hist., Jour., vol. 13, p. 193, Pl. 16, Figs. 8a, b.

Not *Octonaria stigmata* KINDLE, 1912, U. S. Geol. Survey, Bull. 508, p. 115, Pl. 9, Fig. 11.

Carapace subovoid to subreniform in side view; dorsal margin arched, highest in front of middle; ventral margin nearly straight. Left valve overlapping right along hinge, the overlap less marked toward extremities and unknown ventrally.

Surface of valve with a narrow, moderately well-defined marginal flange, about obsolete ventrally, and also poorly developed in the overlapped dorsal part of the right valve; area within flange elevated, with flattened summit; rise to elevated area less abrupt anteriorly than elsewhere. Elevated area marked by about 18 fairly coarse puncta; one row of about 7 or 8 pits extends parallel to the postdorsal, posterior, and ventral margins of the elevated area; about 4 pits form a nearly horizontal row extending posteriorly from the middle of the elevated area; three or four pits form a group near the anterior margin of the area; a stronger pit breeches the dorsal margin of the elevated area somewhat in front of its middle.

Length 0.85 mm., height 0.52 mm.

RELATIONSHIPS: The above description is based on examination of the holotype in the Ulrich and Bassler collections at the United States National Museum, together with study of two silicified right valves and the dorsal half of a silicified carapace, all from the same collections and from the type locality. The specimens were pre-

sumably identified by Ulrich, and are believed by the writers to be conspecific with the holotype. They are figured here for comparison with the Appalachian species formerly identified with *Octonaria stigmata.*

OCCURRENCE: Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky.

Octonaria loculosa Ulrich

(Plate 5, figure 3)

Octonaria stigmata var. *loculosa* ULRICH, 1891, Cincinnati Soc. Nat. Hist., Jour., vol. 13, p. 194, Pl. 16, Fig. 10.

Carapace elongate subovoid in side view, dorsal margin tending to be somewhat truncated, bending rather abruptly into the rounded anterior margin; ventral margin slightly concave. Hingement and overlap unknown.

Surface of valve with a fairly well-defined marginal flange, narrowest ventrally. The flange encloses a more elevated area, with a gently convex surface marked by 35 to 40 pits; the pits are arranged about as in *Octonaria stigmata,* but with the addition of two rows nearly parallel to the anteroventral to ventral margin of the elevated area. A group of three pits, lying a little in front of the middle of the dorsal part of the elevated area, evidently correspond to the pit which breeches the dorsal margin of this area in *O. stigmata.*

Length 0.97 mm., height 0.56 mm.

RELATIONSHIPS: The figured specimen, borrowed from the Ulrich and Bassler collections at the United States National Museum, is illustrated here for comparison with *Octonaria multipunctata* of this paper. It had not been identified, but is close to the holotype of *O. loculosa,* and comes from the same locality and horizon. Further studies should be made of the limits of variation of the ornamentation. As in *O. stigmata,* the pits tend to be arranged in rows by more or less distinct ridges, but these are still rounded and relatively low.

OCCURRENCE: Middle Devonian Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky.

Octonaria multipunctata Swartz and Swain, n. sp.

(Plate 5, figure 4a, b)

Carapace subelliptical to subreniform in side view; dorsal margin broadly arched, rounding gradually into the ends; anterior end most extended below; posterior end apparently more regularly rounded; ventral margin nearly straight. Hingement and overlap not known.

Surface with a narrow marginal flange, weakly developed along the posterior margin and about obsolete ventrally. Remainder of valve more elevated, gently convex, marked by about 55 to 60 rather closely crowded puncta. Beginning with an elongate triangular group in the mediodorsal region, a more or less distinct double row of puncta extends along and just within the anterior and ventral margins of the elevated area. Three additional, poorly defined and somewhat divergent rows extend posteriorly from another subtriangular group lying at the median to anteromedian part of the valve. In outline, the elevated, punctate area is broader posteriorly than anteriorly.

Length 1.02 mm., height 0.52 mm.

RELATIONSHIPS: *Octonaria multipunctata* is established on the internal mold and part of the external mold of a left valve. It is somewhat similar to *O. loculosa* Ulrich, but has about 55 to 60 rather than 30 to 35 puncta. It is closer to *O. deltisulcata*

Swartz (1932), but the latter has only about 40 puncta, and has a large, simple, triangular depression in the dorsomedian part of the elevated area.

OCCURRENCE: Very rare in the Onondaga beds at Clarks Mill, Pennsylvania. Rare and questionable at Berkeley Springs, West Virginia.

Octonaria alticostata Swartz and Swain, n. sp.

(Plate 5, figure 5a-g)

Octonaria stigmata KINDLE, 1912, U. S. Geol. Survey, Bull. 508, p. 115, Pl. 9, Fig. 11.
Not *Octonaria stigmata* ULRICH, 1891, Cincinnati Soc. Nat. Hist., Jour., vol. 13, p. 193, Pl. 16, Figs 8a, b.

Carapace subreniform in side view, the dorsal margin strongly arched, the arch fairly regular, highest slightly in front of middle; ventral margin nearly straight to scarcely concave; ends nearly equal. Judging from the external mold of one right valve, preserving more or less clearly the impression of the edge of the left, the left valve overlaps the right along all margins.

Surface of left valve with a flattened border or marginal flange, broadest dorsally and terminally; the flange very much narrower in the right valve because of the overlap relations. Area within flange bordered by a highly elevated ridge, enclosing three punctate sulci, separated by elevated, sharply crested ridges. One sulcus parallels the anterior margin, extends a short distance parallel to the ventral margin, and at its other end for a longer distance parallel to the dorsal margin, where in the left but apparently not the right valve it tends to breech the bordering ridge. The floor of this sulcus is marked by about 8 or 9 small, rather shallow pits, with an elongated depression rather than a pit at its dorsal end, especially in the right valve; the sulcus is sometimes divided at its anteroventral bend, at least in right valves. A shorter sulcus, with about 8 pits, parallels the postdorsal margin; below and about parallel to it the third sulcus extends from the postventral region forward and slightly upward within the bend of the anterior sulcus; the third sulcus is marked by a pit at each end, and by one or two near its middle.

In the internal molds, the ridges, sulci, and puncta are but weakly represented. No clearly represented adductor scar has been observed in the molds examined.

Length 1.45 mm., height 0.85 mm.

RELATIONSHIPS: Because of the deep sulci and strong ridges, this species is quite distinct in construction from the smaller *Octonaria stigmata* with which it previously has been identified.

OCCURRENCE: Common 25 feet above base of Onondaga at New Bloomfield, rare 5 to 10 feet at Clarks Mill, rare 65 to 70 feet at Warren Point, Pennsylvania. Kindle reports it from 2 miles west of Canoe Creek, Blair County, Pennsylvania.

Genus *Thlipsurella* Swartz

Thlipsurella (?) *curvicristata* Swartz and Swain, n. sp.

(Plate 8, figure 6a-c)

Carapace subreniform to somewhat subovate in outline; dorsal margin broadly convex, the greatest height in front of middle; ends rather sharply rounded, the posterior margin somewhat truncated; ventral margin about straight. Hingement and overlap not known.

Surface of valve moderately convex, rising rather steeply from ventral and dorsal margins, more gradually from posterior margin; anterior slope concave, rising to a low rounded ridge, curved about parallel to anterior margin, and dying out gradually

at either end. Floor of depression behind ridge rises gradually to merge with general surface of valve. Surface otherwise smooth or very nearly so. The internal mold shows very faintly the impression of a fairly large circular subcentral muscle scar.

The holotype measures length 2.7 mm., height 1.15 mm.

RELATIONSHIPS: *Thlipsurella (?) curvicristata* appears to be a member of the elongate and terminally furrowed *T. plicata* section of *Thlipsurella* as described by Swartz (1932). The form of the subterminal ridge and depression is quite different from that of any other members of the group now known.

OCCURRENCE: Rare to common 100 feet above base of the Onondaga beds, New Bloomfield, Pennsylvania.

Genus *Eustephanus* Swartz and Swain, n. g.

Carapace elongate subelliptical to somewhat subreniform in outline, the dorsal margin broadly convex. Hingement and overlap not known.

Surface of valve rather broadly convex; posterior slope concave, the crest at summit of this slope bearing two posteriorly directed short spines. Surface with pits tending to lie in curving furrows, which more or less parallel the dorsal margin.

GENOTYPE and only known species: *Eustephanus catastephanes* Swartz and Swain, n. sp.

RELATIONSHIPS: *Eustephanus* is somewhat suggestive of *Octonaria* Jones, but differs therefrom in the absence of the marginal flange and in the presence of subterminal spines. It is perhaps closer to *Stibus* Swartz and Swain, n. g., but is more elongate in outline, without the tendency toward terminal truncation seen in that genus, does not tend to have the posterior pits concentrated toward the posterior end, and does have the posterior pits as well as the anterior ones situated along the floors of grooves. These differences produce a very considerable difference in aspect, so that with incomplete specimens there is much more danger of confusing *Eustephanus catastephanes* with *Octonaria alticostata* than with any member of the genus *Stibus*.

OCCURRENCE: Known only from the genotype in the Onondaga at New Bloomfield, Pennsylvania.

Eustephanus catastephanes Swartz and Swain, n. sp.

(Plate 5, figure 6a, b)

Carapace subreniform in outline, the dorsal margin broadly convex, the ends rounded, about equal, the ventral margin gently convex. Hingement and overlap unknown.

Surface of valve rising rather steeply from the ventral and dorsal margins; anterior edge expanded, forming a narrow flattened but indistinct border; posterior slope concave, the lower part forming a fairly broad posterior flange, the concavity above the flange continued for a short distance onto the ventral slope; crest at summit of ventral slope bears two posteriorly directed short spines. The surface is ornamented by three grooves, their floors marked by a total of about 15 pits. The posterior half has two of the grooves, convex upward, not quite parallel, arranged in a garlandlike fashion; the third groove, with 5 or 6 of the pits, lies near and about parallel to the anterior and anterodorsal margins; there is an extra pit near the center of the space within this groove. The posterior portion of the anterior groove extends onto the dorsal slope of the valve; the end of the groove curves slightly downward; in the internal mold, a depression due to internal thickening extends from the true end of the groove about to the center of the valve.

The holotype measures length 1.10 mm., height 0.51 mm.

RELATIONSHIPS: In the lack of a marginal flange, the concave posterior slope surmounted by a crest with two posteriorly directed spines, and the pitting of parts of the surface, *Eustephanus catastephanes* approaches *Stibus kothornostibus* in its general construction. The rather marked difference in shape, and virtual restriction of the pits to the floors of garlandlike grooves give it a quite different aspect. When dealing with poorly preserved material and fragments, there is some danger of confusion with the associated *Octonaria alticostata*. With better material, however, the marginal flange, deeper grooves, and higher intervening ridges of the latter species are distinctive features. Furthermore, *alticostata* lacks the posterior spines of *catastephanes*.

OCCURRENCE: Rather rare 25 to 30 feet above base of the Onondaga, New Bloomfield, Pennsylvania.

Genus *Stibus* Swartz and Swain, n. g.

Carapace small; subreniform in outline, the dorsal margin broadly arched, posterior margin rather blunt, anterior margin most extended below. Typically, at least, the hinge of the left valve has a narrow longitudinal groove or rabbet, its lower margin elevated and forming a narrow longitudinal ridge; characters of hinge of right valve less clear. Overlap uncertain, but one external mold shows the left valve with a somewhat questionable overlap over the right.

Surface of valve convex, with a steep, concave posterior slope; crest at top of this slope bearing two small, posteriorly directed spines in the known species. One or more furrows, sometimes replaced by a row of pits, lie near to and about parallel with the anterior to anterodorsal margins; posteriorly, the surface tends to be marked by rather small pits, though these are sometimes absent.

GENOTYPE: *Stibus kothornostibus* Swartz and Swain, n. sp.

RELATIONSHIPS: *Stibus* is provisionally included in the Thlipsuridae because of the subreniform outline and surface sulcation and pitting. Superficially, it approaches *Thlipsurella* Swartz; but in that genus the sulcus where developed is typically submedian rather than terminal, the pittings or depressions tend to be coarser and to be less variable within the species, and spines are not known at the summit of the steep terminal slope, which in that genus has been regarded as anterior, not posterior in position. Both the terminal spines and character of the hinge suggest relationship with *Favulella favulosa*, as hereinafter described.

OCCURRENCE: Known at present only in the Middle Devonian Onondaga beds of central Pennsylvania and West Virginia.

Stibus kothornostibus Swartz and Swain, n. sp.

(Plate 6, figure 3a-j)

Carapace small, subreniform in outline; the dorsal margin broadly convex; ventral margin straight to slightly concave; posterior margin relatively blunt; anterior margin somewhat oblique, most extended below; greatest height about at anterior end of hinge. Hinge as in description of genus.

Surface rising rather steeply from margins, then becoming more gently convex over the general surface; posteriorly, there is a high concave slope, its summit forming a crest or angulation, which bears two well-developed posteriorly directed spines, one at the dorsal and one at the ventral part of the crest. Close to and nearly paralleling the anterior margin is a fairly long curved furrow or sulcus, one or the other end tending to split off as a separate, rounded pit; a short distance from the dorsal

end of the main sulcus is a second, shorter one, its floor typically divided into three pits. Posteriorly, the surface is marked by as many as 35 to 40 small, rounded, fairly deep pits, never extending onto the slope beneath the posterior angulation but commonly spreading to or a little in front of the middle of the valve. In the holotype, the pits are arranged in nearly longitudinal rows; in other specimens, their arrangement is variable and often irregular, and in material here retained in the species their number may drop to 15 or even to 10.

In internal molds, the external ornament is as a rule but weakly reflected, and the carapace is evidently very thin at the floors of the depressions. Adductor scars are not clearly shown. The surface of the mold tends to be somewhat depressed above and generally a little in front of the middle; in part this is due to inner thickening of the valve but in part it is a reflection of the external sulci.

The holotype measures length 0.75 mm., height 0.38 mm.

RELATIONSHIPS: The generic relationships have already been discussed; the species is not close to any known forms except those next described.

OCCURRENCE: Rare 65 feet, common 25 feet above base of Onondaga at New Bloomfield; common to abundant at Clarks Mill, Mount Rock, and Newton Hamilton, rare at McVeytown, Pennsylvania; common at Cooper Mountain, West Virginia.

Stimus kothornostibus var. *paucipunctus*

Swartz and Swain, n. var.

(Plate 6, figure 4a-e)

Carapace subreniform in outline; posterior margin somewhat truncated; anterior margin most extended below. Hinge and overlap as in description of genus.

Surface of valve convex; crest at summit of steep posterior slope bearing two posteriorly directed small spines; closely adjacent to crest are about 5 to 8 small pits; a curved sulcus lies close to and about parallel with the anterior margin; near the dorsal end of this sulcus is a second much smaller one.

The holotype measures length 0.68 mm., height 0.4 mm.

RELATIONSHIPS: This varietal name is used with some hesitancy for specimens in which the posterior pits are restricted to a small area close to the posterior end and are only about 5 to 8 in number; the secondary, anterodorsal sulcus is also small. In size of carapace, shape, convexity, characters of the small posterior spines, and character of the anterior furrow, there is, however, little change from the more typical specimens of *Stibus kothornostibus*, and the material studied seems to show continuous variation from the one type to the other.

OCCURRENCE: Rare 65 feet, common 25 feet above base of Onondaga at New Bloomfield; common at Clarks Mill, Mount Rock, and Newton Hamilton, Pennsylvania; rare at Cooper Mountain, West Virginia.

Stibus unisulcatus Swartz and Swain, n. sp.

(Plate 6, figure 5a-f)

Carapace subreniform in outline; dorsal margin broadly arched, tending to be highest in front of middle; posterior margin somewhat truncated; anterior margin tending to be most extended below. Direct evidence on hinge and overlap not obtained.

Surface convex, rising steeply from margins; posterior slope concave, forming a narrow posterior flange; crest at top of posterior slope bearing two small posteriorly directed spines. Near and about parallel to anterior margin is a fairly deep curved sulcus, its outer rim commonly a little higher than the surface along its posterior

margin. Two or three pits are commonly developed just anterior to crest at top of posterior slope but are absent in some specimens.

The holotype measures length 0.73 mm., height 0.42 mm.

RELATIONSHIPS: *Stibus unisulcatus* differs from *S. kothornostibus* and its variety *paucipunctus*, as here described, in the loss of the secondary, anterodorsal furrow, and in the near obsolescence or complete absence of the posterior pits. The concavity of the posterior slope is perhaps a little more pronounced. The whole assemblage is notable for the relative instability of the surface depressions; and, in so far as they occur together, as at Clarks Mill, the three forms may represent variants in an interbreeding assemblage. In the writers' judgment, the observed differences in sculpture have no bearing on either ontogenetic stages or dimorphism.

OCCURRENCE: Common to abundant in collections from Onondaga beds at Clarks Mill, rare to common at Mount Rock and Newton Hamilton, Pennsylvania; rare at Berkeley Springs, West Virginia.

Stibus seriopunctus Swartz and Swain, n. sp.

(Plate 6, figure 6)

Carapace subreniform to subovate in outline; dorsal margin broadly arched, highest a little in front of middle; posterior margin somewhat truncated; anterior margin most extended below. No direct data on hinge and overlap.

Surface rises steeply from margins, is gently convex over remaining surface. Angulation at summit of concave posterior slope bears two posteriorly directed spines. Near to and paralleling the anterior and anterodorsal margins is a row of about 7 rounded, rather deep pits; the posterior to middle parts of the general surface are also marked by rather deep pits which, in the holotype, are 20 in number and tend to form nearly longitudinal rows.

The holotype measures length 0.7 mm., height 0.4 mm.

RELATIONSHIPS: *Stibus seriopunctus* is based on external molds of only two valves, but these are closely similar in the details of their ornament. The row of pits paralleling the anterior and anterodorsal margins is clearly a modification of the anterior and anterodorsal furrows of *S. kothornostibus;* in that species, the floor of the anterodorsal furrow is commonly broken into three pits, which remain more or less confluent, and there is a tendency for pits to separate off at the ends of the anterior furrow.

OCCURRENCE: Rare 25 to 30 feet above base of the Onondaga, New Bloomfield, Pennsylvania. A few poorly preserved specimens from 85 to 90 feet above base of the Onondaga at Berkeley Springs, West Virginia, have provisionally been referred to this species.

Genus *Favulella* Swartz and Swain, n. g.

Carapace subovate to somewhat subreniform in outline. Hinge of left valve with a main longitudinal grove, a fairly long anterior accessory groove somewhat oblique to main groove, and a questionable, short posterior accessory groove. These grooves must receive the slightly modified dorsal edge of the right valve. Left valve apparently overlaps right along ventral margin but not at ends, so that right valve is more elongate than left. The dorsal margin of the left valve also seems to project higher than that of right valve.

Surface of valve with a submarginal ridge, sometimes obsolete dorsally; the ridge sets off a marginal flange, more or less obsolete ventrally in both valves, and dorsally

as well in the right valve; the posterior limb of the ridge is extended into two well-developed posteriorly-directed spines. The area enclosed by the ridge is honeycombed by rather coarse, close-set puncta, irregular in shape and size; these are absent over a submedian smooth spot.

GENOTYPE: *Bythocypris favulosa* Jones.

RELATIONSHIPS: In the presence of a marginal flange enclosing a strongly marked area, *Favulella* somewhat resembles the more strongly and abundantly punctate types of *Octonaria;* but it differs from that genus in the closer punctation, the submedian smooth spot, and the subterminal spines. It approaches *Ponderodictya* Coryell and Malkin (1936) which is weakly punctate, has a submedian smooth spot, small subterminal spines, and a low short ridge near the anterior margin. *Ponderodictya,* however, lacks the margin flange of *Favulella,* and the left valve overlaps the right along all the margins.

The family relationships of *Favulella* are not at all satisfactorily understood at the present time. The genus has been placed for convenience of description and in a very provisional manner in the Thlipsuridae. Its characters ally it rather strongly with *Ponderodictya,* which has been referred by Coryell and Malkin to the Cytherellidae; but the writers have been reluctant to place *Favulella* in the latter family in view of its strongly developed submarginal ridge and other ornaments, and since the evidence provided by the shape, overlap, and hinge relations does not greatly favor classification in the one family as compared to the other, at least with present knowledge.

Favulella favulosa (Jones)

(Plate 7, figures 1-23; Plate 8, figure 8)

Bythocypris favulosa JONES, 1886, Am. Geol., vol. 4, p. 338, Pl. opp. p. 342, figs. 1, 2a-c—CLAYPOLE, 1903, Am. Geol., vol. 32, p. 247—KINDLE, 1913, U. S. Geol. Survey, Bull. 508, p. 114, Pl. 9, figs. 14, 15 (not fig. 13).

Carapace typically subovate in outline, sometimes becoming more elongate, somewhat subreniform, the right valve lower and proportionately more elongate than the left. Greatest height about at anterior end of hinge proper: dorsal margin, especially in left valve, tending to be partially truncate along hinge line; anterior margin obliquely rounded, most extended below, higher than posterior margin, which tends to be truncated, somewhat extended below. In left valve, the main part of hinge consists of a longitudinal groove, extending from a little in front of middle of valve almost to posterior end; there is a well-developed accessory groove in front of and making a small angle with the main groove; this anterior groove is marked by very fine transverse striations. There is a shorter, less well-defined posterior groove which may not be part of the hinge. Internal molds of right valves provide less satisfactory evidence of hinge characters, but the edge presumably forms ridges which fit into the grooves of the left valve. Overlap relations not unquestionably shown by material studied. However, molds of two right valves show impressions of terminal rabbets, apparently to receive ends of the shorter left valve; in one external mold of parts of conjoined valves, the left valve widely overlaps the right along the ventral margin but not along the ends. Although the latter specimen may be modified by some displacement of the valves, the overlap relations which it displays will explain the characteristic difference in outline of the two valves.

Surface of valve with a marginal flange best developed terminally and also in the left valve extending around the dorsal margin but obsolete ventrally. Inside the flange a well-developed submarginal ridge extends from near the anterodorsal region, paralleling the anterior and ventral margins, to the postventral bend; it

becomes weaker along the posterior margin, where it bears two strong stout spines, which project backward and a little outward from the conjunction plane of the valves. The submarginal ridge is commonly weak or nearly obsolete along the dorsal margin but is occasionally well developed there. Area inside submarginal ridge marked by numerous rather deep pits of variable size and shape, sometimes occurring as unequal pairs or triplets. The outer pits tend to be arranged concentrically with the submarginal ridge; to some extent the remaining pits are obscurely parallel to this outer row but often they are devoid of any real arrangement. Just in front of middle of valve is a nonpitted more or less circular smooth area surrounded by a subcircular row of pits. The pits do not extend onto the areas outside the submarginal ridge except dorsally, where they tend to form an outer row, especially if this limb of the ridge is reasonably well developed. The remainder of the flange commonly bears small distant pustules.

Internal molds show hinge and overlap features as described. The submarginal ridge and posterior spines are weakly reflected, as is the surface pitting; the floors of the carapace pits accordingly must be thin. At the position of the submedian smooth spot is a shallow depression tending to have a slightly raised rim. The surface of the mold is somewhat depressed between this subcentral marking and the dorsal margin.

The external mold of a left valve, shown in Figure 1 of Plate 7 measures length 1.54 mm., height 0.9 mm.

Relationships: *Favulella favulosa* is one of the most abundant and persistent of the species of the Onondaga beds of the area covered by this investigation. It shows a considerable range in form and ornament, as is brought out in the above description and in the illustrations. In addition to the normal difference in proportion of the two valves, the specimens show variations in proportionate length, in the strength of the dorsal portion of the submarginal ridge and development of the row of pits on its outer side, and in the coarseness of the pitting.

Occurrence: Abundant 25 feet, common 65 feet above base of Onondaga beds at New Bloomfield; common to abundant at Clarks Mill, Mount Rock, Newton Hamilton, and Warren Point, Pennsylvania; common at Cooper Mountain and Berkeley Springs, West Virginia.

Favulella dicarinella Swartz and Swain, n. sp.

(Plate 8, figure 7a-d)

Carapace elongate oval to somewhat subreniform; dorsal margin gently convex, bending rapidly into the rounded ends; ventral margin about straight to slightly concave. Hingement and overlap not directly known, presumably as in the closely related *Favulella favulosa*.

Surface of valve with a continuous submarginal ridge paralleling dorsal as well as free margins; posterior portion of ridge extended into two spines projecting posteriorly and a little outward from conjunction plane of valves. The ridge sets off a marginal flange, obsolete ventrally; dorsally, shallow grooves in the flange tend to project as shallow puncta set into the dorsal side of the submarginal ridge. Area enclosed by flange gently convex, marked by numerous close-set coarse deep puncta, absent over a rather small circular submedian smooth spot; the puncta are rather irregular in shape and size; the outer ones tend to be arranged concentrically with the submarginal flange; the inner ones tend to be rather irregularly arranged except for modifications due to two narrow ridges which are quite constant in position; one of these ridges extends in a horizontal direction posteriorly from the postventral

part of the submedian smooth spot; the other ridge extends obliquely in an anteroventral, postdorsal direction, tangential to the anterodorsal margin of the smooth spot.

The holotype measures length 1.25 mm., height 0.6 mm.

RELATIONSHIPS: *Favulella dicarinella* is closely related to *F. favulosa* from which it was evidently derived, and which it seems to completely replace in the uppermost Onondaga beds at New Bloomfield. It differs from that species in its more elongate, more equal ended form, and especially in the development of the two narrow ridges adjacent to the submedian smooth spot. The dorsal portion of the submarginal ridge is more strongly developed than is typical in *favulosa*.

OCCURRENCE: Very rare 25 and 65 feet, rare 80 feet, common to abundant 100 feet above base of the Onondaga beds at New Bloomfield, Pennsylvania.

Genus *Ranapeltis* Bassler

Carapace elongate subtrapezoidal to subreniform in outline; dorsal margin tending to be somewhat truncated along position of hinge, where it about parallels the long, nearly straight to slightly concave ventral margin; anterior and rounded, posterior and extended and angulated below, so that greatest length is near ventral margin. Hingement and overlap not very clear; hinge apparently thickened without appreciable overlap; left valve overlaps somewhat on right along middle of ventral edge, but expanded ventroterminal parts of edge seem to have simple contact.

Surface of valve rather strongly convex; ventral slope steep, tending to form a flattened ventrum; edges are somewhat expanded in the ventroterminal parts, but no *Octonaria*-like flange is developed. In known species, there are two narrow surface ridges, their main parts nearly straight and paralleling the ventral margins, their ends bent dorsally.

Internal molds show the impression of a well-marked circular adductor scar, slightly anterior to the middle.

GENOTYPE: *Ranapeltis typicalis* Bassler (1941).

RELATIONSHIPS: The name *Carinaria* was used for this genus by the writers when this paper was submitted in July, 1940. It has seemed desirable to retain the generic analysis and discussion which were then presented, although Bassler's recently proposed name must be given precedence. The outline of *Ranapeltis* is similar to that of *Octonaria octoformis*, the genotype of *Octonaria* described by Jones from the Middle Silurian Wenlock beds of England. It would also be possible to conceive of modification of the rather simple looplike ridges of *octoformis* into the narrow ridges of *Ranapeltis*. On the other hand, the shape and ornaments do not at all resemble those of the various species from the Middle and Lower Devonian of the Appalachian region, which are now included in *Octonaria;* indeed, the differences in form and ornament as compared to these octonarids and to the species of *Thlipsura* and other undoubted Thlipsuridae are so marked as to raise grave doubts as to inclusion of *Ranapeltis* in that family. On the other hand, the rounding of one end and ventral extension and angulation of the other, the near parallelism of the hinge and ventral margins, the flattening of the ventrum, the ventroterminal expansion of the edges, and the strong subcircular adductor scar are all strongly suggestive of the Lower Devonian *Acanthascapha pentagonalis* Swartz (1936); in fact, if *Ranapeltis* was derived from any of the ostracodes known from the Lower Devonian of the Appalachian region by far the most likely ancestor is *pentagonalis*. These relationships strongly argue that *Ranapeltis* should be referred to the Beecherellidae, in spite of the surface ornaments, the similarities to *Octonaria octoformis*, and the lack of truly beecherellidlike spines. In any event it is to be hoped that future discoveries will bring to light

connecting links which will give more positive evidence with regard to the relationships of the genus.

The comparative orientation of *Ranapeltis* has been especially troublesome. The rounded end has been regarded as anterior because it is higher and especially because the adductor is closer to this end. The angulated end is slightly but not very greatly the more extended in terms of the hinge. This orientation is very satisfactory for comparison with *Acanthoscapha pentagonalis*. On the other hand, the angulated end of *Octonaria octoformis* is currently regarded as anterior (*see* Bassler, 1934), and in *O. stigmata* as described in this paper the anterior end projects somewhat below; but this end in *stigmata* is much higher than the other and is much more extended in terms of the hinge. The aspect is so different that comparison between *stigmata* and *Ranapeltis* does not provide a satisfactory basis for orientation.

Occurrence: The three species of *Ranapeltis* here described all occur in the Middle Devonian Onondaga beds of central Pennsylvania and northeastern West Virginia. Bassler has described two species from the Camden chert of Tennessee.

Ranapeltis dicarinata Swartz and Swain, n. sp.

(Plate 6, figure 1a-f)

Carapace elongate subtrapezoidal to somewhat subovoid in outline; dorsal margin truncated, the hinge about half to two thirds the greatest length; posterior margin angulated and most extended below; anterior margin rounded, projecting a little more below than above, somewhat higher than the posterior; ventral margin scarcely concave. Hinge without pronounced overlap; free edge of left valve overlaps right at middle of ventral margin, but apparently not elsewhere.

Surface of valve strongly convex, rising steeply from the ventral margin, so that the ventrum of the carapace is distinctly flattened; dorsal slope also rather steep and, in internal molds, tending to overhang so as to indicate that the hinge is somewhat thickened. Ventral edge of right valve with an external low ridge, apparently acting as a stop for the edge of the left and absent on the left valve; this small ridge bears anteroventrally a row of tiny spinelets. At the summit of the rise from the ventral edge is a long narrow but well-elevated ridge, its posterior end straight, its anterior end stronger and hooked back on its dorsal side; the tip of the anterior hook typically touches the anterior part of a more dorsal, much shorter, somewhat sinuous ridge, with a hooklike curve at each of its ends. Toward the dorsal margin the surface bears coarse, fairly distant pustules.

In the internal molds, the surface ridges are fairly well reflected; there is a clear impression of a well-marked, circular adductor scar situated a little in front of the middle; the surface bordering the ends is somewhat flattened.

The holotype measures length 1.82 mm., height 0.84 mm.

Relationships: *Ranapeltis dicarinata* differs from both *trilateralis* and *R. divergens* in the manner of curvature of the ends of the surface ridges.

Occurrence: Fairly common 25 to 30 feet above base of the Onondaga beds, New Bloomfield, Pennsylvania.

Ranapeltis trilateralis Swartz and Swain, n. sp.

(Plate 5, figure 7a-i)

Carapace elongate subtrapezoidal in outline; dorsal margin tending to be truncated along hinge which is about half to two thirds of total length; posterior end angulated and projecting below, extending somewhat farther beyond hinge than does the more

rounded anterior end; anterior end commonly a little higher than the posterior, or ends about equal. Hingement and overlap not shown by material studied.

Surface of valve strongly convex, rising steeply from ventral edge, and almost equally sharply from dorsal margin; areas bordering the terminal margins are somewhat flattened. The surface bears two very broadly U-shaped, narrow, closely placed ridges; their ventral limbs are convex upward as seen in side view, weaker near their middle, more strongly elevated where they bend sharply upward into the converging vertical parts. The ventral limb of the outer ridge lies at about the summit of the ventral slope; its middle part is poorly defined on its ventral side; the vertical limbs extend about halfway to the dorsal margin. The ventral limb of the inner ridge is about three fourths length of valve; it tends to have a short forward and upwardly directed branch just in front of its middle; the vertical limbs reach virtually to the dorsal margin at about the ends of the hinge. In some specimens, here retained in the species, the ventral limbs of both ridges are nearly or quite obsolete at their middle part. Surface apparently without fine ornament; there is, however, a very small outwardly directed spinelet just within the tip of the posterior angulation, at least in the right valve.

Internal molds generally show the impression of a well-marked, circular adductor scar just in front of the middle of the valve; the external ridges are weakly reflected; the dorsal slope tends to be overhanging, apparently due to thickening of the valve hinge.

The holotype measures length 1.24 mm., height 0.68 mm.

RELATIONSHIPS: *R. trilateralis* differs from *R. dicarinata* primarily in the different form of the surface ridges; it also lacks the dorsal pustules of that species, and the posterior angulation is perhaps somewhat less sharp. It is not very clear whether the posterior angulation of *R. dicarinata* does or does not possess a small spinelet at the tip of the posterior angulation, such as is seen in *R. trilateralis*.

OCCURRENCE: Common 5 to 10 feet above base of the Onondaga beds, Clarks Mill, Pennsylvania.

Ranapeltis divergens Swartz and Swain, n. sp.

(Plate 8, figure 5a-d; Plate 6, figure 2)

Carapace subreniform in outline, the outline of the dorsal margin perhaps more flattened on right than on left valves; anterior margin broadly rounded, somewhat more extended below; posterior margin most extended below, angulated where it bends abruptly into the nearly straight or slightly concave ventral margin. Hingement and overlap not known.

Surface of valve rather strongly convex, rising sharply from the ventral margin, rather steeply from the dorsal margin, more gradually from the terminal margins, being flattened and somewhat concave especially near the posterior edge. The surface bears two ridges; the inner ridge has a nearly straight ventral section, a little more than half the length of the valve; this limb of the ridge may be obsolete at its middle part; the ends of the ridge are bent sharply into nearly vertical dorsally directed limbs, which in the holotype end well below the dorsal margin. In some specimens, the vertical limbs almost reach the dorsal margin; this may represent a difference between the two valves, the shorter limbs being seen in left valves. The outer ridge has a longer horizontal portion, commonly bent upwards somewhat at its middle; the anterior limb curves rather sharply upward about parallel to anterior limb of inner ridge, and tends to become obsolete about halfway to the dorsal margin; posteriorly the outer ridge diverges more widely from the inner one, extends for

some distance parallel to the ventral margin, then bends sharply upward and forward to form a small hook. Surface appears to be otherwise smooth.

Length 1.4 mm., height 0.8 mm.

RELATIONSHIPS: This species is very close to *Ranapeltis trilateralis*, but differs therefrom chiefly in the relatively lesser length of the ventral segment of the inner ridge, and the markedly greater divergence of the posterior part of the outer ridge with development of a small hook at its posterior end. Further collecting is needed to check the question as to whether the differences in length of the vertical limbs of the inner ridge are simply differences in the characters of the two valves. The differences in the outline of the dorsal margins of the left as compared to right valves in the most complete external molds appears to be a valve difference, and the other species should be further studied with respect to this feature. With molds such as those on which this study has been based it is not always possible to be confident as to all details of the margins.

As known at the present time, *R. trilateralis* is distinctive of the lowest Onondaga of the New Bloomfield region, and is replaced by *R. divergens* at higher levels.

OCCURRENCE: Rare to common, 65, 80, and 100 feet above base of the Onondaga at New Bloomfield, rare to common at Mount Rock, Newton Hamilton and Warren Point, rare and somewhat questionable at Swatara Gap, Pennsylvania; rare to common, Berkeley Springs, West Virginia.

Family ROPOLONELLIDAE Coryell and Malkin

Genus *Euglyphella* Warthin

Euglyphella sp.

(Plate 8, figure 4)

A squeeze from the incomplete external mold of a left valve of a species belonging to the genus *Euglyphella* is figured to help complete the record of Onondaga Ostracoda. The surface is gently convex, and bears low winding ridges, approaching rather closely in character and pattern the ridges of *projecta* Coryell and Malkin (1936, p. 7, Fig. 18). The persistence in detail of pattern of these ridges in *projecta* is not sufficiently indicated to determine whether the specimen here illustrated would fall within the limits of that species, and more specimens are needed from the Onondaga to establish the range in detail of ornament here. Determination of the specific characters must accordingly await further collecting. Length 1.1 mm., height 0.6 mm.

OCCURRENCE: Very rare 75 feet above base of Onondaga beds, 1 mile north of Newton Hamilton, Pennsylvania.

Family BEECHERELLIDAE Ulrich

Genus *Beecherella* Ulrich

Beecherella bloomfieldensis Swartz and Swain, n. sp.

(Plate 8, figure 9a-h)

Carapace elongate subreniform to somewhat subovate in outline; dorsal margin broadly convex, greatest height just in front of middle, anterior margin rather sharply rounded, posterior margin most extended ventrally where it tends to be angulated, ventral margin slightly concave to about straight. In one imperfect mold of part of a carapace, the left valve is shown to overlap somewhat on the right along the ventral margin; hingement and overlap otherwise unknown.

Surface of valve rather strongly elevated, rising steeply from the ventral, more gradually from the dorsal margin, so that the ventrum is more or less flattened, and the bend from the ventral slope to the general surface is rather abrupt although not really angulated; general summit of elevated area flattened; the elevated area projects anteroventrally into a rather blunt extension, and postventrally into a sharper point; each of these extensions has an overhanging under slope, but neither projects beyond the actual edge of the valve. Surface otherwise smooth.

Internal molds show the impression of a well defined circular submedian muscle scar.

Length 1.8 mm., height 0.8 mm.

RELATIONSHIPS: *Beecherella bloomfieldensis* has the subreniform outline, flattened ventrum, and terminally directed spines of *Beecherella*, but is sufficiently different in aspect from the genotype, *B. carinata* Ulrich, as to raise some question regarding the generic classification.

OCCURRENCE: Rare to common 80, abundant 100 feet above base of the Onondaga beds, New Bloomfield, Pennsylvania.

Family BAIRDIIDAE Sars

Genus *Tubulibairdia* Swartz

Tubulibairdia paucitubulis Swartz and Swain, n. sp.

(Plate 5, figures 8a-c)

Carapace elongate subrectangular, the dorsal and ventral margins nearly straight and almost parallel, the ends broadly rounded, with the anterior end projecting a little farther beyond the hinge than does the posterior; hinge about three fourths total length. Hingement and overlap not clear.

Surface of valve strongly convex, most swollen posteriorly, rising steeply from the margins, tending to project slightly above hinge. Surface presumably smooth. Internal molds with relatively few, coarse, irregularly arranged projections, which are also irregular in thickness and height; these represent the inwardly opening tubules characteristic of the valves of the genus.

Length 0.82 mm., height 0.45 mm., maximum convexity about 0.25 mm.

RELATIONSHIPS: *Tubulibairdia paucitubulis* differs from the previously described *T. tubulifera* Swartz (1936) of the Lower Devonian Shriver beds in the fewer and more irregularly placed tubules; also, the dorsal and ventral margins are more nearly parallel, and the posterior margin more regularly rounded.

OCCURRENCE: Rare in collections from Onondaga beds at Clarks Mill, Pennsylvania.

Tubulibairdia multitubulis Swartz and Swain, n. sp.

(Plate 5, figure 9)

Carapace subovate in outline, greatest height about at anterior end of hinge, which truncates dorsal margin and is about half the greatest length. Posterior end somewhat truncated above, most extended about one third distance above ventral edge; anterior end less asymmetrical, most extended just below middle. Hingement and overlap unknown.

Surface of valve most convex about one third distance from posterior end, descending rather regularly toward the margins; dorsal part, at least of right valve, apparently not projecting above hinge. Surface detail not known, presumably smooth. Internal mold shows closely and regularly spaced rounded projections of nearly

uniform size and extending perpendicular to surface of mold; these represent the tubules characteristic of the genus.

The holotype measures length 1.45 mm., height 0.78 mm., maximum convexity about 0.40 mm.

Relationships: *Tubulibairdia multitubulis* is based on the imperfect internal mold of one right valve; nevertheless, the shape of the valve, and especially the arrangement and regularity of the tubules, is so distinctive as to warrant specific recognition.

Occurrence: Very rare, Onondaga beds at Clarks Mill, Pennsylvania.

Genus *Bythocypris* Brady

Bythocypris (?) *perarcuata* Swartz and Swain, n. sp.

(Plate 6, figure 7a, b)

Carapace strongly subreniform in outline, dorsal margin very highly arched, ventral margin straight or scarcely concave; ends rounding into dorsal margin, but sharply angulated where they bend into the ventral margin. Hingement and overlap unknown.

Surface of valve moderately convex, descending regularly to ventral and terminal margins, swollen dorsally and projecting considerably beyond the hinge; in the material studied, the surface is somewhat compressed, so that the convexity is reduced and the dorsal projection is somewhat accentuated. Surface of valve smooth. No adductor scar represented on internal mold.

The holotype measures length 1.24 mm., height 0.81 mm.

Relationships: Because of lack of knowledge of the hinge and overlap relations, the generic position of this species is uncertain. The highly arched dorsum and the termino-ventral angulations provide striking specific characters.

Occurrence: Very rare, Onondaga beds at Clarks Mill, Pennsylvania.

Family Cytherellidae Sars

Genus *Cavellina* Coryell

Cavellina planoloculata Swartz and Swain, n. sp.

(Plate 6, figures 8a-f)

Carapace elongate subovate; posterior margin somewhat truncated, anterior margin more extended and rounded. Hingement and overlap not clear; some of molds of right valves show impressions apparently representing narrow inconspicuous rabbets along the ventral and dorsal margins.

Surface of valve most convex ventroposteriorly. Posterior slope concave, forming a posterior flange; summit of this slope sharply angulated. Surface rising steeply from ventral margin, more gradually from anterior and dorsal margins.

Internal molds of valves show a dorsomedian depression, representing an internal thickening which may have served for attachment of the adductor; this internal thickening is scarcely reflected on the valve exterior and tends to be stronger in the female than in the male valves. The female valves are commonly larger, longer, and somewhat more convex than the males; in the female internal mold, the posterior fourth is separated from the remainder by a furrow, which is open and widened ventrally and disappears dorsally; the furrow represents a vertical internal thickening or ridge, which partially divides off a posterior internal cavity, presumably a female brood pouch; the pouch and ridge are scarcely if at all reflected on the valve

exterior. The summit of the mold of the dimorphic cavity is flattened, lies about in the plane of projection of the remainder of the valve mold and is separated from the posterior slope by a rather marked angulation.

The figured internal mold of a female right valve measures length 1.0 mm., height 0.56 mm., convexity about 0.25 mm.

RELATIONSHIPS: *Cavellina planoloculata* is very close to *Cavellina paraquaesita* Swartz (1936) of the Lower Devonian Shriver beds but has a somewhat more pronounced posterior angulation and flange; more importantly, in the internal mold the summit of the swelling representing the dimorphic chamber is flattened and distinctly less elevated, lying about in the plane of projection of the remainder of the mold rather than being strongly raised above it.

OCCURRENCE: Common in collections from Onondaga beds at Mount Rock, Lewistown; very rare and somewhat questionable at Clarks Mill, Swatara Gap, and Warren Point, Pennsylvania.

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Explanation of Plates

Plate 1.—Leperditellidae, Aechminidae, Drepanellidae, Hollinidae

Figure 1.—*Aparchites* (?) *lenticularis* Swartz and Swain, n. sp. (a-c) Lateral views of cotypes, the internal molds of a right and of two left valves, x25; (a) Shows the impression of the thickening of the free edge of the right valve, strongest ventrally; (d) Squeeze from external mold of a left valve, x25, incomplete ventrally. Incomplete internal mold of a valve, x20, showing impression of adductor scar, and perhaps belonging in a different species; (a-d) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (e) 70 to 80 feet above base of Onondaga, Mount Rock, Pennsylvania (p. 416).

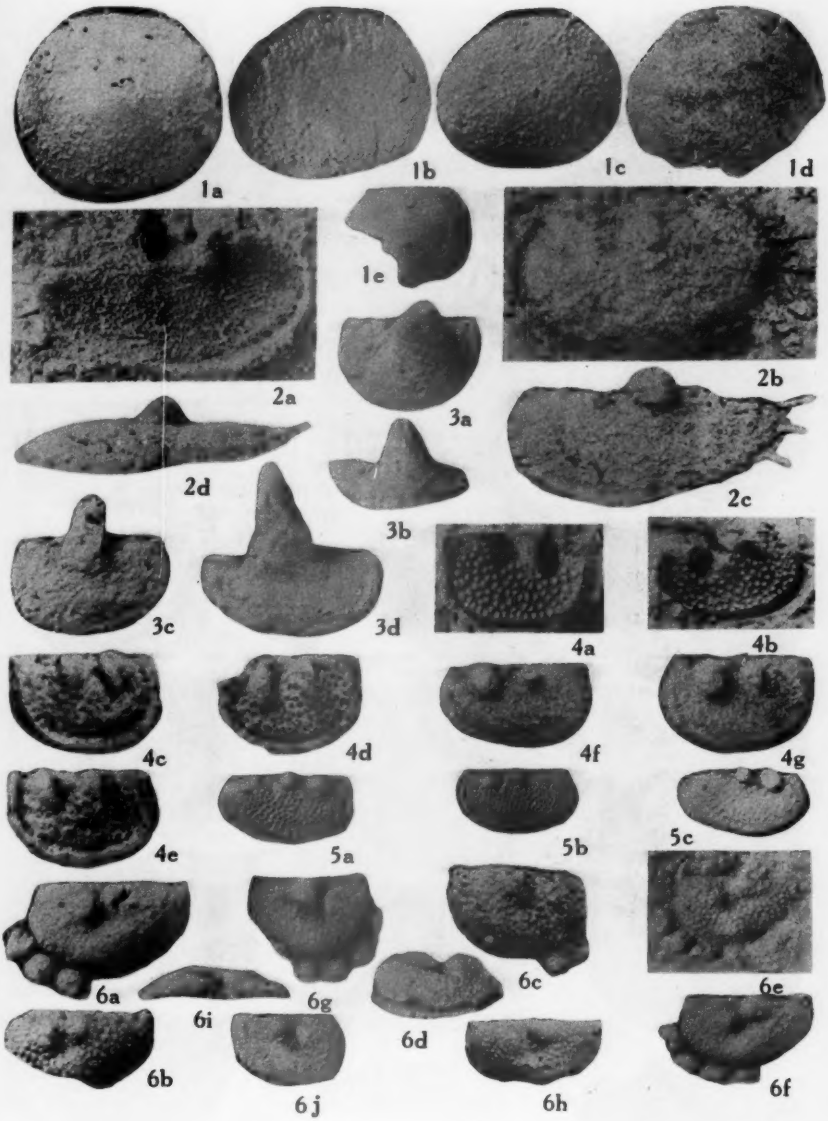
Figure 2.—*Aechmina* (?) *fimbriata* Swartz and Swain, n. sp. (a, b) Views of holotype, the external and internal molds of a right valve, x30. In (a) note impressions of base of dorsal spine, the pit, the surface pustules, the openings leading into molds of the posterior spines, the molds of three anterior spinelets, uncovered where the edge of the mold is broken. The edge is incomplete anteroventrally, anteriorly, and dorsally; the valve shape is better shown in (b) although here the anterior edge is buried; (c-d) Lateral and ventral views of squeeze from the incomplete external mold, x30, 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 417).

Figure 3.—*Aechmina crassicornis* Swartz and Swain, n. sp. (a, b) Lateral and ventral views of squeeze from holotype, the external mold of a right valve, x30. The valve is somewhat crushed, and the spine is bent too far from the plane of the valve edges; (c) Internal mold of a left valve x30, showing shape; (d) Squeeze from external mold of a left valve, x30, the low terminomarginal ridges somewhat stronger than in (a). The dorsal margin is incomplete; (a-c) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (d) 70 to 80 feet above base of Onondaga, Mount Rock, Pennsylvania (p. 417).

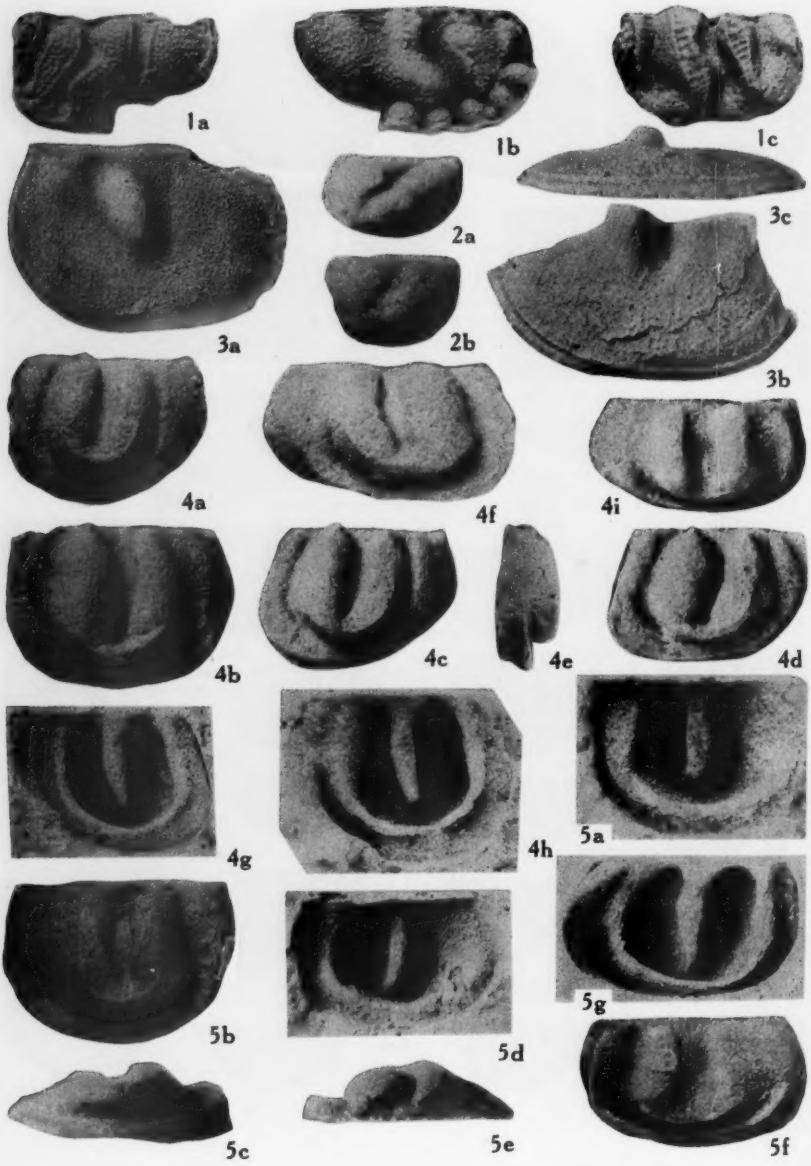
Figure 4.—*Ulrichia pluripuncta* Swartz. (a, b) External molds of a left and a right valve, x30, showing form of marginal ridge and dorsal nodes, arrangement and size of pits, and especially the impression of the nonpunctate sulcus between the nodes; (c-e) Squeezes from external molds of a right and two left valves, x30; (f, g) Internal molds of two left valves, x30, 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 424).

Figure 5.—*Ulrichia elongata* Swartz and Swain, n. sp. (a, c) Squeeze from external mold of a right valve, the holotype, and internal mold of same, x30; (b) Squeeze from external mold of a left valve, x30, the sulcus between the nodes defined ventrally by a narrow rim, 70 to 80 feet above base of Onondaga, Mount Rock, Pennsylvania (p. 425).

Figure 6.—*Parabolbina parvinoda* Swartz and Swain, n. sp. (a, b) Internal mold of a female left valve, the holotype, and squeeze from incomplete external mold of same, x30. In (a) a fourth segment presumably should be represented at the postventral end of the frill. In (b) the anterodorsal angle as well as the anteroventral region is incomplete, but the surface pustules are well shown; (c) Squeeze from external mold of a female right valve, x30, incomplete anteriorly, but showing the small spine on the postventral slope; (d) Squeeze from incomplete external mold of another female right valve, x30, preserving the postventral spine, and showing the row of tiny pits in a groove just inside the free edge; the frill is so thin that the dental stopping scarcely entered its mold; (e, f) Squeeze from incomplete external mold of a female left valve, and internal mold of same, x30, (e) is the only specimen preserving the remarkable anterodorsal spine; (g) Internal mold of a female right valve, x30, (h, i) Lateral and dorsal views of squeeze from ventrally incomplete mold of a left valve, x30, apparently representing a male individual; (j) Internal mold of a male right valve, x30; (a-c) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (d-j) 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 425).



LEPERDITELLIDAE, AECHMINIDAE, DREPANELLIDAE, HOLLINIDAE



TETRADELLIDAE, HOLLINIDAE, ZYGOBOLBIDAE, DREPANELLIDAE

PLATE 2.—TETRADELLIDAE, HOLLINIDAE, ZYGOBOLBIDAE, DREPANELLIDAE

Figure 1.—*Ctenoloculina punctocarinata* Swartz and Swain, n. sp. (a) Squeeze from holotype, the external mold of a left valve, x27, showing external form of the anteroventral frill, the finely punctate summits and narrow rims of the ridges; (b, c) Internal mold of a right valve, showing impressions of compartments on under side of frill, and squeeze from incomplete external mold of same, x30. The postdorsal angle is incomplete in (b); in (c) the punctate surfaces of the ridges are narrower than in (a); (a) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (b, c) Onondaga limestone at Swatara Gap, Pennsylvania (p. 427).

Figure 2.—*Ctenobolbina* (?) *ventricosa* Swartz and Swain, n. sp. (a) Lateral view of holotype, the internal mold of a left valve, x30; (b) Squeeze from external mold of a left valve, x30, the margins incomplete; (a) 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania; (b) 60 to 65 feet above base of Onondaga, Warren Point, Pennsylvania (p. 426).

Figure 3.—*Kloedenia rectangularis* Swartz and Swain, n. sp. Views representing holotype, x11½; (a) internal mold of left valve, nearly complete except postdorsally; (b, c) lateral and ventral views of squeeze from incomplete external mold of same specimen, showing the faintly pustulose surface, very narrow submarginal ridge, and, in (c), the row of very fine pustules along the ventral margin. Onondaga beds, Cooper Mountain, West Virginia (p. 428).

Figure 4.—*Bollia ungula* Jones. (a-d) Squeezes from external molds of four left valves, x25, showing variations in shape, but persistence of ventral crest and dorsal nodes of the inner ridge; (e) Posterior view of squeeze from external mold of a right valve, x25, showing characteristic flattened summit, outer angulation, and overhang of ventral part of marginal ridge, and the much greater elevation of the inner ridge; (f) Squeeze from external mold of an elongate right valve, x25; (g, h) External molds of two left valves, x25; (g) shows well the furrow formed by crest of inner ridge, and is the original of the squeeze in (c); (i) Internal mold of a right valve, x25. About 25 to 30 feet above base of Onondaga beds, New Bloomfield, Pennsylvania (p. 418).

Figure 5.—*Bollia platyloba* Swartz and Swain, n. sp. (a-c) View of holotype, the external mold of a right valve, and lateral and ventral views of squeeze from it, x25. Note flattening of posterior limb of inner ridge due to dorsal continuation of crest. The rise of the postventral margin is incomplete, as seen in (c); (d, e) External mold of a right valve, and dorsal view of squeeze from it, x25; (f) Internal mold of a left valve, x25; (g) External mold of a left valve, x25; this is the only specimen referrable to *platyloba* found in the collections from *Bollia ungula* zone at New Bloomfield; 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania, except (g) 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 419)

PLATE 3.—DREPANELLIDAE

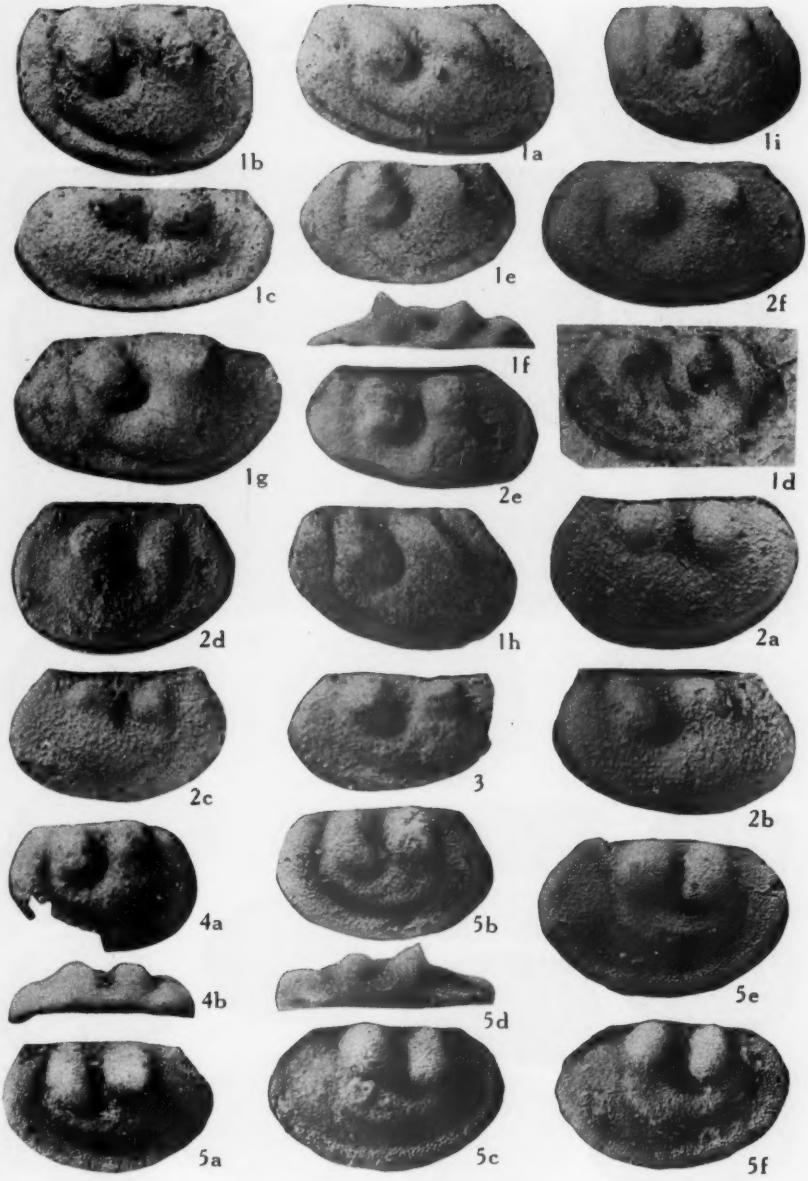
Figure 1.—*Bollia diceratina* Swartz and Swain, n. sp. All figures about x25; (a) Squeeze from holotype, the external mold of a left valve; (b) Squeeze from external mold of a shorter left valve, showing surface pustulation; summit of posterior node of inner ridge is damaged; (c) Squeeze from external mold of an elongate right valve; (d-f) External mold of a left valve, showing impressions of surface pustules and spines of knobs of inner ridge, and lateral and dorsal views of squeeze from same; (f) especially shows the characteristic spines of the knobs of the inner ridge; (g) Squeeze from external mold of a left valve, the postdorsal angle incomplete; (i) Squeeze from external mold of a short, convex left valve. (a-c, h, i) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (d-f) 70 to 80 feet above base of Onondaga, Mount Rock, Pennsylvania; (g) Onondaga beds, Cooper Mountain, West Virginia (p. 421).

Figure 2.—*Bollia diceratina* Swartz and Swain, n. sp. Internal molds of valves, (a, c, d) representing right valves, (b, e, f) left valves. Specimens illustrated by (b) and especially (e) show impressions of well-defined hinge grooves of the left valve; (d) also gives evidence of hinge grooving in the right valve, but such grooving was not observed in other right valve molds. Specimens illustrated by (a-c) are somewhat swollen postventrally and may well represent female individuals; (a-c) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (d-f) Onondaga beds, Cooper Mountain, West Virginia. Comparative orientation of species of *Bollia* illustrated on this plate is clearly shown by (a) anterior position (as here described) and (b) anterior curvature of sulcus inside inner ridge; (c) greater swelling of anterior limb of inner ridge. The difference in the cardinal angles is not striking, although the posterior angle tends to be better defined. These features carry the orientation to *B. planojugosa* and *B. spinomuralis* (Plate 4) without difficulty. In all these species, the greatest height is behind the middle; in *B. diceratina* there is a strong backward swing, but this is less marked in the others. Comparative orientation of *B. ungula* and *B. platyloba* (Plate 2) is less clear. Using the supposed anterior position and swing of the sulcus and greater swelling of the anterior limb of the inner ridge, the latter species are placed with the greatest height in front of the middle, and the carapace swing is toward the front (p. 421).

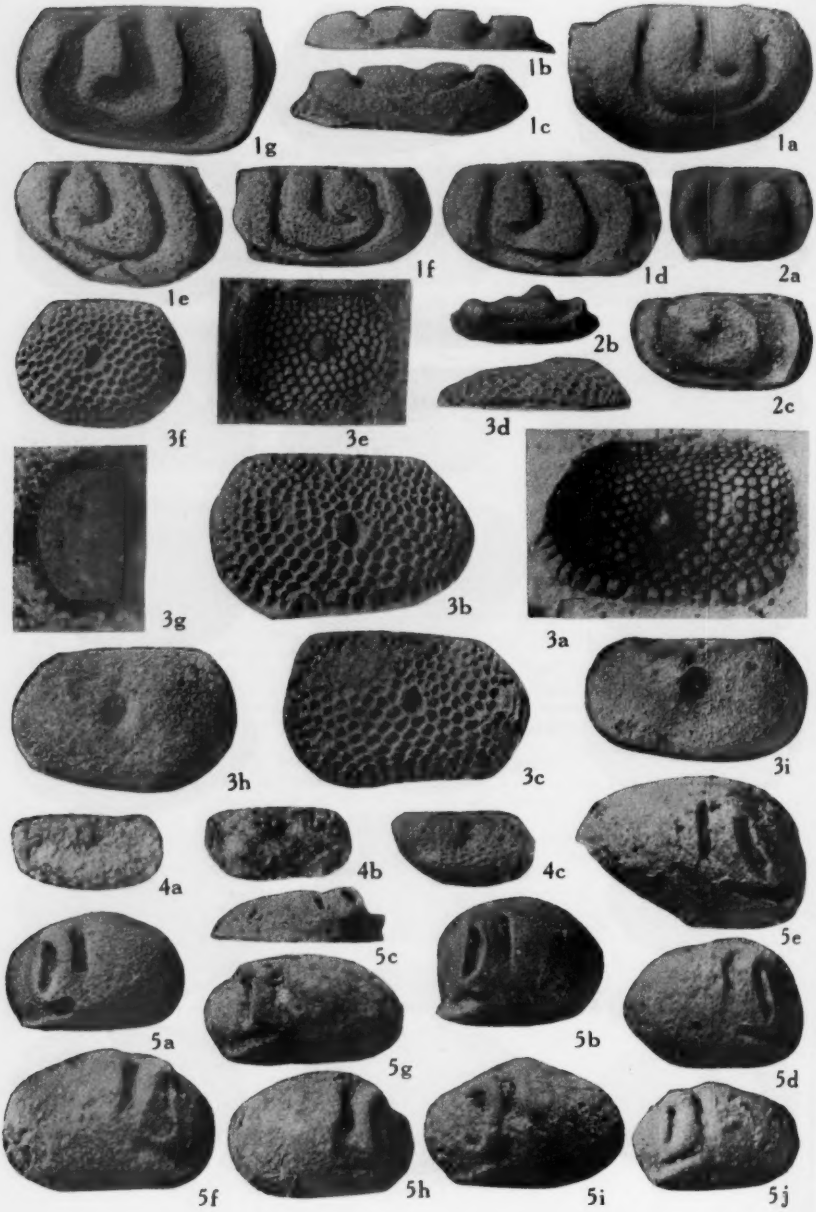
Figure 3.—*Bollia diceratina* var. *fimbriata* Swartz and Swain, n. var. Squeeze from holotype, the external mold of a left valve, x25. The squeeze did not penetrate far into the molds of the anteroventral spines, so does not show their length. The posterior margin is incomplete. Note anterior swing of specimen; 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 422).

Figure 4.—*Bollia obesa* Ulrich. Side and dorsal views of a topotype, a silicified left valve, x30, showing nearly symmetrical outline, rounded summits of knobs, narrow groove between ridges. Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky. U. S. National Museum No. 41,331 (p. 420).

Figure 5.—*Bollia hindei* Jones. All are silicified valves, about x25; (a, b) Two left valves; (c, d) Lateral and dorsal views of a right valve, showing pointed summit of posterior knob of inner ridge, rounded summit of anterior knob; (e, f) Two right valves, showing moderate width of postventral part of inner ridge, wide flattened area between posterior parts of inner and outer ridges. Hamilton group, Moscow beds, Thedford, Ontario; from collections in U. S. National Museum (p. 419).



DREPANELLIDAE



DREPANELLIDAE, KIRKBYIDAE, THLIPSURIDAE

PLATE 4.—DREPANELLIDAE, KIRKBYIDAE, THLIPSURIDAE

Figure 1.—*Bollia planojugosa* Swartz and Swain, n. sp. (a-c) Side, dorsal, and ventral views of squeeze from holotype, the external mold of a right valve, (a, b) x25, (c) x23; note narrow furrows and marked flattening of ridge summits; (d-f) Squeezes from external molds of two left and one right valve, x25; note thickening of ventroposterior bend of inner ridge; (g) Internal mold of left valve, showing apparent narrowing of ridges and widening of furrows; 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 423).

Figure 2.—*Bollia spinomuralis* Swartz and Swain, n. sp. (a, b) Side and ventral views of holotype, the internal mold of a right valve, x30; (c) Internal mold of an elongate left valve, x30; 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 423).

Figure 3.—*Amphissites* (?) *altireticulatus* Swartz and Swain, n. sp. (a, b) View of holotype, the external mold of a right valve, and squeeze of same, x25. The ventral margin is not quite complete; (c) Squeeze from external mold of a right valve, x25; (d) Ventral view of squeeze from external mold of a left valve, x25, showing character of ventral edge; (e, f) External mold of a short left valve, and squeeze from same, x25; (g) Anterior view of internal mold of a right valve, x25, preserving part of the external mold, and illustrating the height of the reticulations and thinness of the floors and walls of the pits; (h, i) Internal molds of two left valves, showing deep pit corresponding to the submedian external depression, bordered dorsally by a small depression; (a, b, e-h) About 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania; (c, d, i) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 429).

Figure 4.—*Kirkbyella rhomboidalis* Swartz and Swain, n. sp. (a, b) Views of holotype, the internal mold of a right valve, and squeeze from external mold of same, x37; (c) Squeeze from external mold, x37, incomplete postventrally, but preserving the surface pits; (a, b) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (c) 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 430).

Figure 5.—*Thlipsura thyridioides* Swartz and Swain, n. sp. (a-c) Views of holotype; internal mold of a left valve, and lateral and dorsal views of squeeze from its external mold, x30; (d, e) Squeezes from incomplete molds of two right valves, x31; (f-j) Internal molds of three left (g, i, j) and two right (f, h) valves, showing some variations in outline; (a-c) Onondaga beds, Cooper Mountain, West Virginia; (d-j) 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania, (e, j) from the loose material donated by Bradford Willard (p. 431).

PLATE 5.—THLIPSURIDAE, BAIRDIIDAE

Figure 1.—*Thlipsura* sp. Internal mold of a right valve, x30. Onondaga limestone, Swatara Gap, Pennsylvania (p. 431).

Figure 2.—*Octonaria etigmata* Ulrich. Views of topotypes, x30: two left valves, and dorsal view of ventrally incomplete carapace, all silicified, illustrated for comparison with *Octonaria alticostata*. Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky. United States National Museum, Number 41,705 (p. 432).

Figure 3.—*Octonaria loculosa* Ulrich. View of topotype, a silicified left valve, x30. Jeffersonville limestone, Falls of the Ohio, Louisville, Kentucky. Collections of the United States National Museum (p. 433).

Figure 4.—*Octonaria multipunctata* Swartz and Swain, n. sp. Views of holotype, x32: internal mold of a right valve, and squeeze from its incomplete external mold; 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 433).

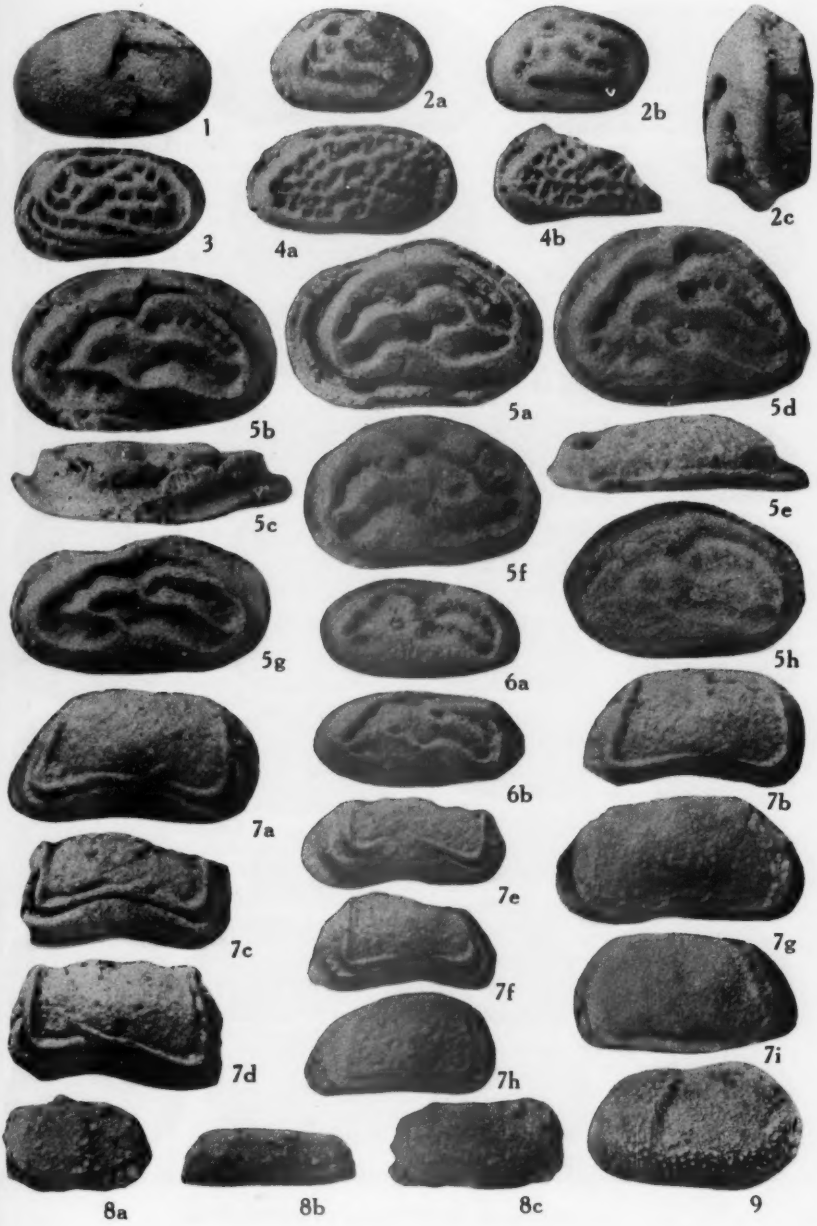
Figure 5.—*Octonaria alticostata* Swartz and Swain, n. sp. All x30. (a) Squeeze from holotype, the external mold of a right valve, preserving mold of most of overlapping edge of left; (b, c) Side and dorsal views of squeeze from external mold of a left valve, showing marginal flange; (d, e) Side and ventral views of squeeze from external mold of a left valve, the flange incomplete postdorsally; (f) Squeeze from external mold of a right valve, the margin apparently about complete—*compare* with broad marginal flange of opposite valve; (g) Squeeze from external mold of elongate left valve, incomplete dorsally; note that dorsal end of anterior furrow breaches the outer ridge, as in (b); (h) Internal mold of a left valve. All from about 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania; (d, e) From loose material donated by Willard (p. 434).

Figure 6.—*Eustephanus catastephanes* Swartz and Swain, n. g., n. sp. Views of holotype: internal mold of a left valve, and squeeze from external mold of same, x30. The posterior spines are imperfectly shown in (b); 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 435).

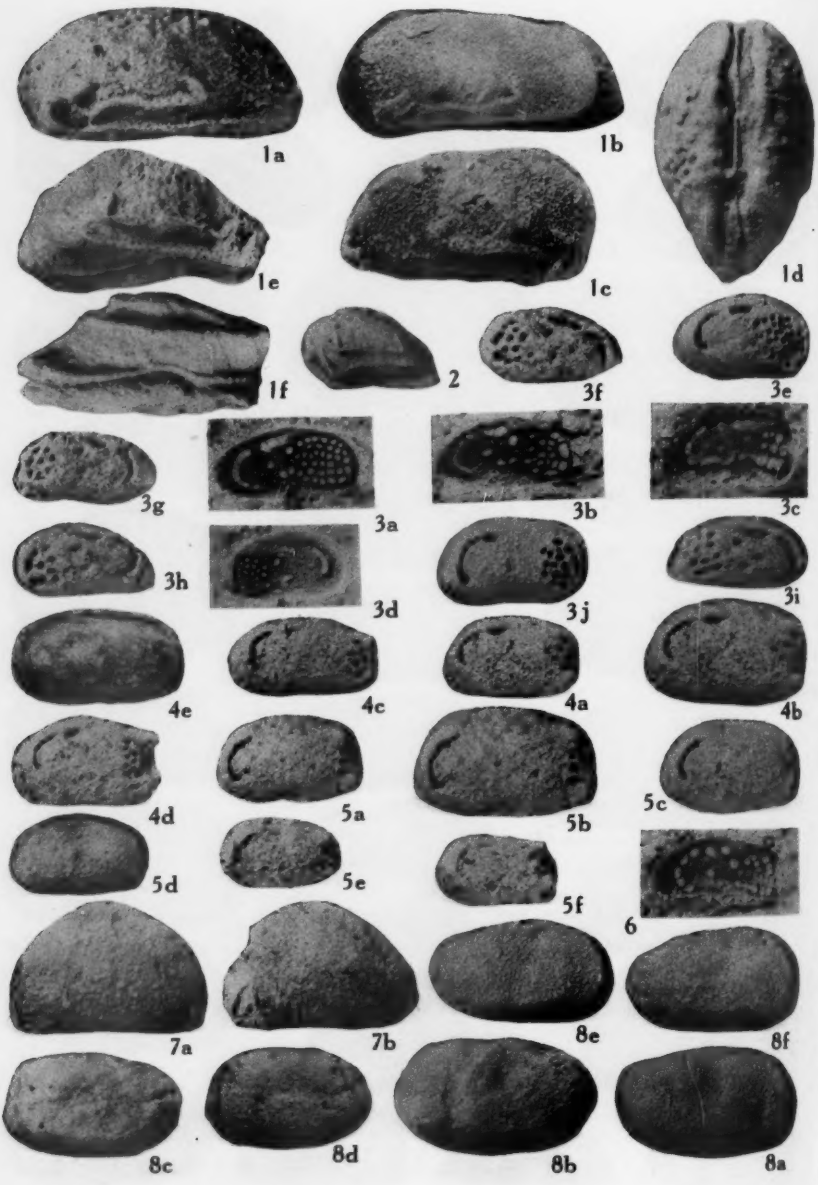
Figure 7.—*Ranapeltis trilateralis* Swartz and Swain, n. sp. All about x30; (a) Squeeze from holotype, an almost complete external mold of a right valve; (b-d) Squeezes from external molds of two right and one left valves, the first nearly complete; (e, f) Squeezes from external molds of two valves, in which the middle part of the ventral limbs of the ridges are more or less obsolete; (g) Internal mold of a right valve, showing impression of the muscle scar; the posterior margin is incomplete; (h, i) Internal molds of a right and a left valve, the margins not well preserved. All from 5 to 10 feet above base of Onondaga beds at Clarks Mill, Pennsylvania (p. 442).

Figure 8.—*Tubulibairdia paucitubulis* Swartz and Swain, n. sp. (a) The holotype, an internal mold of a right valve, x30; (b, c) Ventral and lateral views of internal molds of two other right valves, x30; 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 445).

Figure 9.—*Tubulibairdia multitubulis* Swartz and Swain, n. sp. The holotype, an internal mold of a right (?) valve, x24, showing molds of the small, regularly spaced tubules; part of the surface is broken, removing the tubule molds; the outline, however, seems to be reasonably complete; 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 445).



THLIPSURIDAE, BAIRDIIDAE



THLIPSURIDAE, BAIRDIIDAE, CYTHERELLIDAE

PLATE 6.—THLIPSURIDAE, BAIRDIIDAE, CYTHERELLIDAE

Figure 1.—*Ranapeltis dicarinata* Swartz and Swain, n. g., n. sp. All about x25; (a, b) views of holotype: squeeze from external mold of a left valve, and internal mold of the same; in (a) the margins are incomplete, but the surface ridges and dorsal pustules are well shown; in (b) the margins are complete, and the mold of the adductor scar is well preserved; (c, d) Right side and dorsal views of internal mold of a carapace, bearing silicified remnants of the test; (e, f) Tilted right and ventral views of squeeze from part of external mold of specimen shown in (c, d); in (f) note the tiny spinose projections on the anteroventral part of margin of the right valve. About 25 feet above base of Onondaga, New Bloomfield, Pennsylvania; material donated by Willard (p. 442).

Figure 2.—*Ranapeltis divergens* Swartz and Swain, n. sp. (*Also see* Plate 8, figure 5.) Squeeze from distorted external mold of a small left valve, x26; 60 to 65 feet above base of Onondaga, Warren Point, Pennsylvania (p. 443).

Figure 3.—*Stibus kothornostibus* Swartz and Swain, n. g., n. sp. All about x30; (a) View of holotype, the external mold of a right valve, showing the resemblance to a boot-print which led to the generic and specific names; (b) External mold of another right valve, showing some variation in ornament; the molds of the posterior spines have been uncovered, showing their length and direction; (c, d) External molds of a right and a left valve, showing variations in the surface ornament; (e-i) Squeezes from external molds of a left and of four right valves, showing variations in ornament. The posterior spines are not represented; (j) Internal mold of a left valve, showing abnormal reflection of the surface ornament; the internal molds are commonly almost smooth, and are similar to the molds shown in Figures 4e, 5d. (a, d, e) From 25 to 30 feet above base of Onondaga, New Bloomfield, Pennsylvania; (c) Material from New Bloomfield, donated by Willard; (b, f-h) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (i, j) 60 to 65 feet above base of Onondaga, Mount Rock, Pennsylvania (p. 436).

Figure 4.—*Stibus kothornostibus* var. *paucipunctus* Swartz and Swain, n. var. (a, b) Squeeze from holotype, the external mold of a left valve, x30 and x39, showing the few posterior pits; the basal parts of the posterior spines are represented; (c, d) Squeezes from external molds of two left valves, x30, showing essential persistence of characters; (e) Internal mold of a left valve, x38, showing impressions of the hinge grooves; (a-d) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (e) 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 437).

Figure 5.—*Stibus unisulcatus* Swartz and Swain, n. sp. (a, b) Squeeze from holotype, the external mold of a left valve, x30 and x39, showing loss of secondary, anterodorsal furrow, and the few posterior pits. The spines are closely similar to those shown in Figure 3b; in the squeezes, only their basal parts are represented. (c, d) Squeeze from external mold of a left valve, and internal mold of same, x30. (e, f) Squeezes from external molds of two left valves, x30. 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 437).

Figure 6.—*Stibus seriopunctus* Swartz and Swain, n. sp. View of holotype, the external mold of a right valve, x30, showing impressions of the anterior row of pits. Material donated by Willard from about 25 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 438).

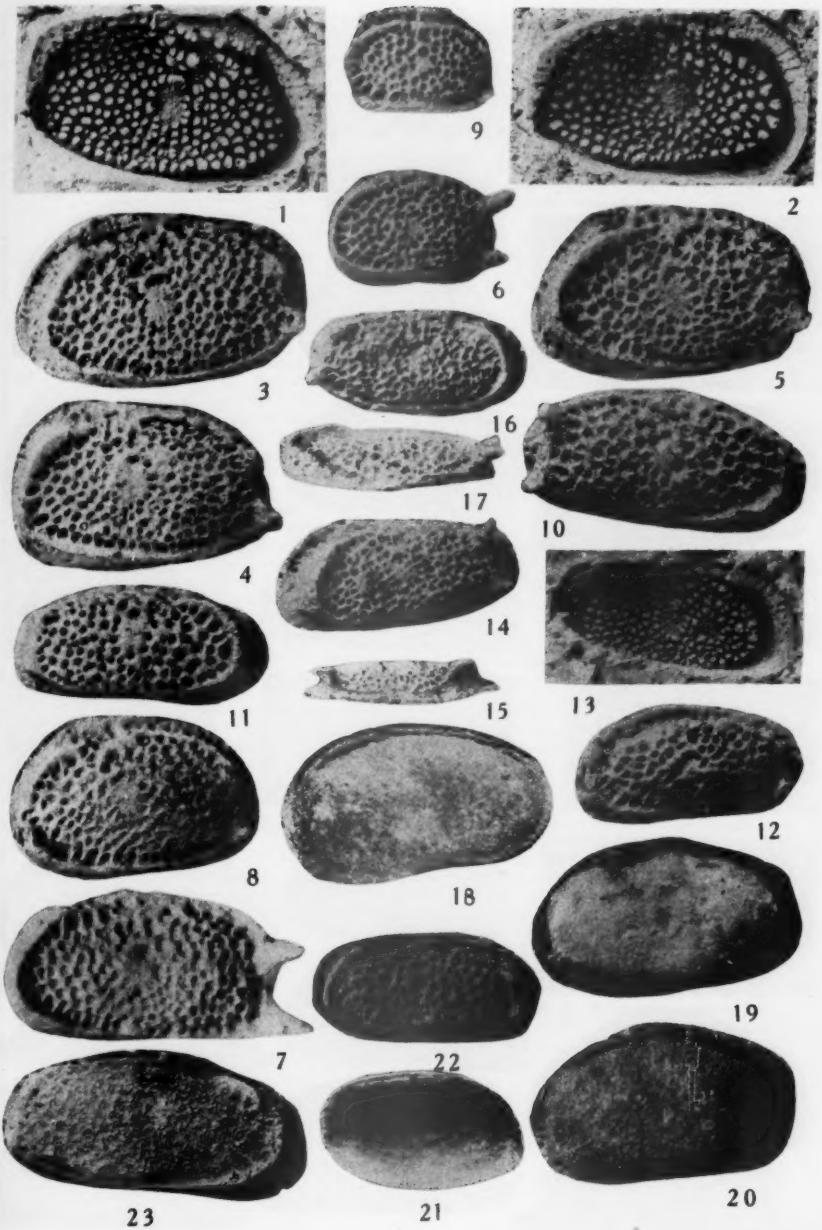
Figure 7.—*Bythocypris* (?) *perarcuata* Swartz and Swain, n. sp. Views of holotype, x25 : internal mold of a valve, and squeeze from incomplete external mold of same. The molds are somewhat flattened by pressure, and the dorsal arcuation may be a little accentuated. This is the only known specimen; whether it should be regarded as a left or right valve is uncertain. From 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania (p. 446).

Figure 8.—*Cavellina planoloculata* Swartz and Swain, n. sp. All about x30; (a) View of holotype, the internal mold of a female left valve, showing mold of internal posterior chamber, and of the dorsomedian internal thickening; (b) Internal mold of a female right valve; (c, d) Internal mold of a male right valve, somewhat crushed, and squeeze from external mold of same, the latter showing the strong angulation at summit of the posterior slope; (e, f) Internal mold of elongate male left valve, and squeeze from external mold of same. The anterior part of the dorsal margin seems to be not quite complete. 70 to 80 feet above base of Onondaga, Mount Rock, Lewistown, Pennsylvania (p. 446).

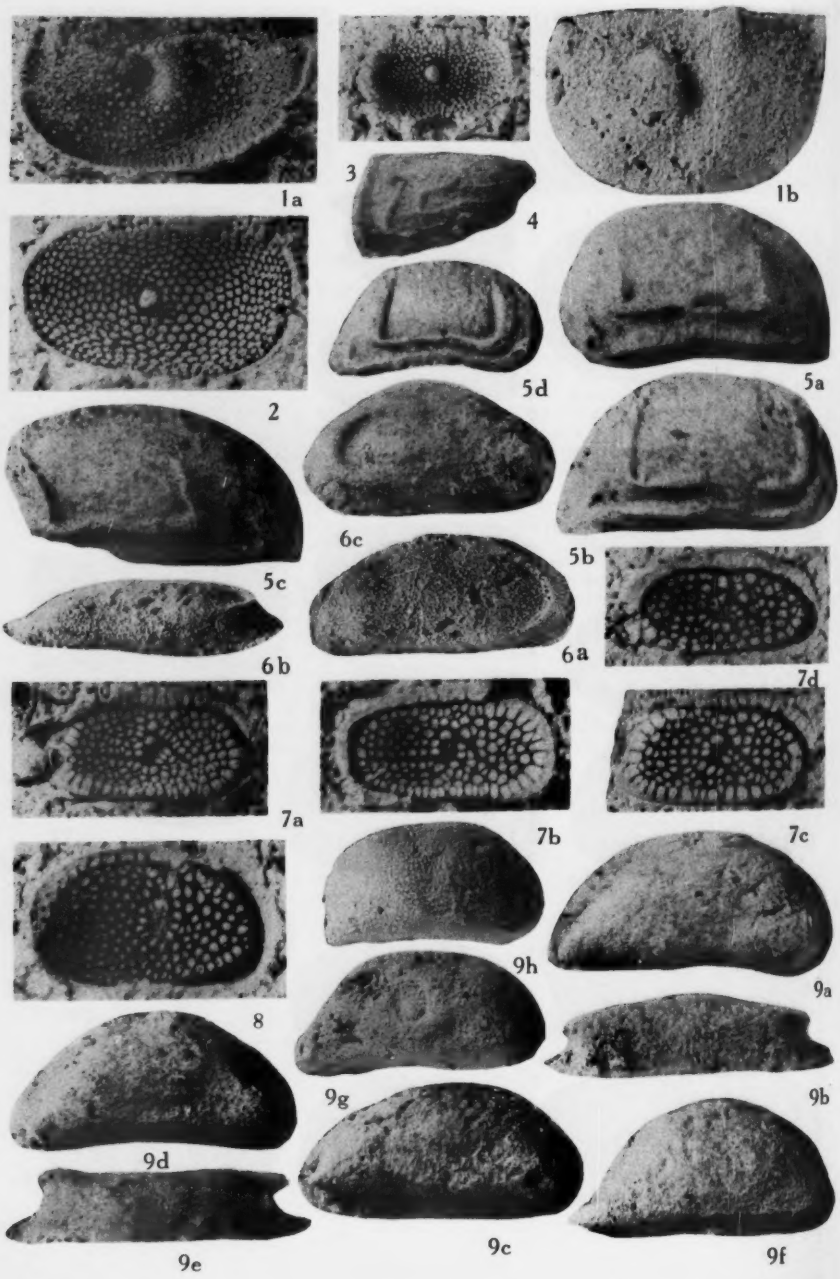
PLATE 7.—THLIPSURIDAE

Figures 1-23.—*Favulella favulosa* (Jones) Swartz and Swain, n. g., all figures about x30, except 15 and 17, x25. (1-4) External molds of two left valves, and squeezes from them, showing typical shape of this valve, the poorly developed dorsal section of the submarginal ridge, the coarse reticulation, the posterior spines, which are imperfectly represented in the squeezes. In Figures 1 and 2, note impression of pustules of the marginal flange; (5) squeeze from mold of another left valve; (6, 7) Squeezes from molds of two left valves, the margins incomplete, the posterior spines better represented because their impressions in the molds were uncovered; (8, 9) Squeezes from external molds of two left valves, showing maximum development of the dorsal limb of the submarginal ridge, and of the pits on its outer side; (10, 11, 17) Squeezes from external molds of two right valves, showing the more elongate form, and dorsal view of the first; (12) Squeeze from external mold of a relatively elongate left valve; (13-15) External mold of an elongate left valve, with relatively fine surface pits, the submarginal ridge obsolete dorsally; and side and dorsal views of squeeze from the same; (16) Squeeze from external mold of a right valve, with relatively fine pits; (18-20) Internal molds of three left valves, showing weak reflection of submarginal ridge, posterior spines, and surface pits, and preserving the impressions of the hinge structures. Striation of the anterior groove is well illustrated in Figure 20; anterior and posterior termination of the main groove is indicated in Figure 18. The submedian depression representing the muscle scar shows in maximum development in Figure 19; (21) Squeeze from internal mold of a left valve, showing form of the hinge grooves; (22) Internal mold of a more elongate left valve, with stronger reflection of the surface pits; (23) Internal mold of a large right valve.

(1-5, 10, 11, 13-17, 19, 23) 5 to 10 feet above base of Onondaga, Clarks Mill, Pennsylvania; (6, 9, 12) about 25 feet above base of Onondaga at New Bloomfield, Pennsylvania; (22) 70 to 80 feet above base of Onondaga, Mount Rock, Pennsylvania; (7, 8, 18, 20, 21) from Cooper Mountain, West Virginia (p. 439).



THLIPSURIDAE



ZYGOBOLBIDAE, KIRKBYIDAE, ROPOLONELLIDAE, THLIPSURIDAE, BEECHERELLIDAE

PLATE 8.—ZYGOBOLBIDAE, KIRKBYIDAE, THLIPSURIDAE, ROPOLONELLIDAE, BEECHERELLIDAE

Figure 1.—*Kloedenia* (?) *fililimbata* Swartz and Swain, n. sp. (a) View of holotype, the external mold of a right valve, x30, showing impressions of the puncta of the general surface, and of the radial threadlike elevated lines of the border. (b) Internal mold of a left valve, x30, showing the form of the median and posterior lobes. Lesser height of the holotype may be due to compression. 100 feet and 80 feet, respectively, above base of Onondaga beds, New Bloomfield, Pennsylvania (p. 428).

Figure 2.—*Amphissites* (?) *altireticulatus* Swartz and Swain, n. sp. External mold of a right valve, x25, the puncta slightly smaller than in the typical material from the lower part of the Onondaga near New Bloomfield. 85 to 90 feet above base of Onondaga, Berkeley Springs. West Virginia (p. 429).

Figure 3.—*Amphissites* (?) *altireticulella* Swartz and Swain, n. sp. View of holotype, the external mold of a small left valve, x23, margins somewhat incomplete except anteriorly; showing the impressions of the very small surface puncta. 75 feet above base of Onondaga beds, 1 mile northwest of Newton Hamilton, Pennsylvania (p. 430).

Figure 4.—*Euglyphella* sp. Squeeze from imperfect external mold of a left valve, x25, showing the low winding ridges. The mold is somewhat incomplete ventrally and posteriorly. 75 feet above base of Onondaga beds, 1 mile northeast of Newton Hamilton, Pennsylvania (p. 444).

Figure 5.—*Ranapeltis divergens* Swartz and Swain, n. sp. (a) Squeeze from holotype, the external mold of a left valve, x30, showing very nearly the true outline, the divergent ridges, and the short vertical limbs of the inner ridge. (b) Squeeze from external mold of a right valve, x30, the anterior margin perhaps not quite complete. The posterior hook of the outer ridge is well shown; the vertical limbs of the inner ridge are long. Note the relatively greater dorsal truncation. (c) Squeeze from somewhat distorted and anteriorly incomplete mold of a left valve, x30 showing posterior outline, and short vertical limbs of inner ridge. (d) Squeeze from internal mold of a small right valve, x30, the ridges more closely placed than typical. (a) 70 feet above base of Onondaga, 1 mile northwest of Newton Hamilton, Pennsylvania; (b-d) 100 feet, 65 feet, and 80 feet, respectively, above base of Onondaga, New Bloomfield, Pennsylvania (p. 443).

Figure 6.—*Thlipsurella* (?) *curvicristata* Swartz and Swain, n. sp. (a, b) Side and slightly tilted ventral view of holotype, the internal mold of a large right valve, x15. (c) Squeeze from external mold of a smaller left valve, x20. 100 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 434).

Figure 7.—*Favulella dicarinella* Swartz and Swain, n. sp. (a) View of holotype, the external mold of a left valve, x30, showing impressions of the submarginal ridge and of the two small ridges adjacent to the submedian smooth spot. The impressions of the posterior spines have also been uncovered, so that the impression of the posterior margin has been removed. (b-d) External molds of left valves, showing the persistence in position of the two small ridges; these ridges are however weaker in (c) and (d), which represent the rarer, earlier occurrences of the species. (a, b) 100 feet, (c) 25 feet, (d) 65 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 440).

Figure 8.—*Favulella favulosa* (Jones) Swartz and Swain, n. g. Mold of a characteristic left valve, x30. 65 feet above base of Onondaga, New Bloomfield, Pennsylvania (p. 439).

Figure 9.—*Beecherella bloomfieldensis* Swartz and Swain, n. sp. (a, b) Side and ventral views of squeeze from holotype, the external mold of a right valve, x25, showing the outline of the valve, and the terminally directed projections or spines. (c-f) Squeezes from external molds of 3 right valves, with dorsal view of the second, all x25. The margins of the first and second are about complete; the posterior margin of the third is missing. The elevated area of the second has an unusually triangular shape. (g, h) Internal molds of 2 right valves, x25, showing impressions of the muscle scar; the differences in shape appear to be due to distortion and some imperfections of the margins. (a, b, f-h) 100 feet, (c-e) 80 feet above base of Onondaga beds, New Bloomfield, Pennsylvania (p. 444).